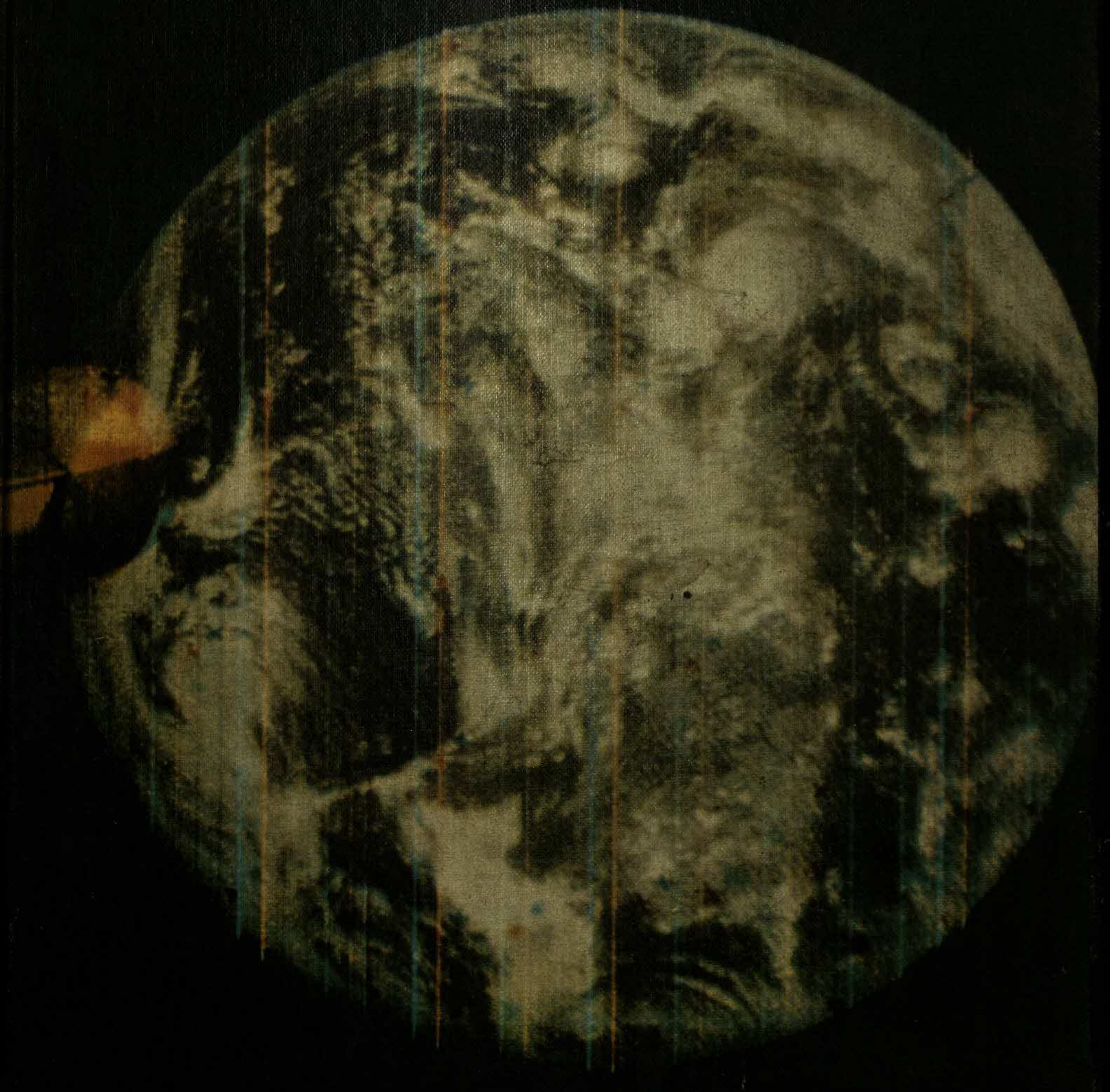
LEWIS AND POTTER

The Teaching of Science in the Elementary School

second edition



Chapter 21

SUMMARY OF PROCESS SKILLS—MACHINES

	Inquiries																
Process Skills for Critical Inquiry*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Observing	✓	✓	✓	✓													
Classifying	✓	✓															
Measuring	✓																
Recognizing space, time relationships																	
Recognizing number relationships	✓																
Communicating	✓	✓	✓	✓													
Inferring	✓	✓	✓	✓													
Predicting																	
Formulating hypotheses																	
Making operational definitions	✓	✓	✓	✓													
Controlling and manipulating variables	✓																
Experimenting	✓																
Interpreting data	✓																
Formulating models	✓			✓													

* Arthur H. Livermore, "The Process Approach of the AAAS Commission on Science Education," *Journal of Research in Science Teaching* (1964), II, 271–82.

Chapter 35

SUMMARY OF PROCESS SKILLS—ELECTROMAGNETIC WAVES

	Inquiries																
Process Skills for Critical Inquiry*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Observing	✓	✓	✓	✓	✓	✓	✓	✓	✓								
Classifying	✓	✓	✓	✓	✓	✓	✓	✓	✓								
Measuring				✓	✓	✓	✓	✓									
Recognizing space time relationships				✓	✓	✓											
Recognizing number relationships				✓	✓	✓		✓									
Communicating	✓	✓	✓	✓	✓	✓	✓	✓	✓								
Inferring		✓	✓	✓	✓	✓	✓	✓	✓								
Predicting					✓	✓		✓									
Formulating hypotheses					✓			✓									
Making operational definitions	✓	✓	✓	✓	✓	✓	✓	✓	✓								
Controlling and manipulating variables		✓	✓	✓	✓		✓	✓									
Experimenting		✓	✓	✓	✓	✓	✓	✓									
Interpreting data				✓	✓	✓		✓									
Formulating models	✓	✓	✓	✓	✓			✓									

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* Arthur H. Livermore, "The Process Approach of the AAAS Commission on Science Education," *Journal of Research in Science Teaching* (1964), II. 271–82.

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STATE INSTITUTE OF EDUCATION
Govt. of West Bengal

The Teaching of Science in the Elementary School

The Teaching of Science

PRENTICE-HALL, INC., ENGLEWOOD CLIFFS, NEW JERSEY

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second edition

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The Teaching of Science in the Elementary School, second edition

Lewis / Potter

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Englewood Cliffs, New Jersey

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Current printing (last digit):

10 9 8 7 6 5 4 3 2 1

13-895623-5

Library of Congress catalog card number:

76-102133

Printed in the United States of America

*PRENTICE-HALL INTERNATIONAL, INC., London
PRENTICE-HALL OF AUSTRALIA, PTY. LTD., Sydney
PRENTICE-HALL OF CANADA, LTD., Toronto
PRENTICE-HALL OF INDIA PRIVATE LTD., New Delhi
PRENTICE-HALL OF JAPAN, INC., Tokyo*

Preface

This book will be helpful to the following educators who work with science education: the *college professor of science education*; the *science consultant* who guides and helps elementary school teachers and administrators; the *science specialist* who teaches in elementary schools; the *classroom teacher* who sometimes feels inadequate when confronted with the necessity of teaching science; the *administrator* who is helping his faculty plan a good science program; and the *student teacher* who wants to become familiar with some of the experiences and methods successful teachers have used.

This book contains the kind of specific help which educators have requested and found valuable. It emphasizes the kinds of inquiries that interest children, and it contains suggestions for using the process skills. The process skills are tools for pursuing critical inquiries and for gaining understandings and concepts. We hope the book will challenge educators, and thus children, to look for other and different ways of their own to approach and solve the critical inquiries suggested. We also hope the book encourages both teachers and children to identify, attack, and solve other inquiries in which they are personally interested.

We wish to express our thanks to the public school system of Glens Falls, New York and to the administrators there for permitting many of the chapters, while still in the manuscript stage, to be tested in the classrooms of the elementary schools. Very sincere thanks are extended to the Glens Falls classroom teachers who participated in this pretesting of the book.

We want to express our appreciation to the following people:

Douglas Aust
R. A. Atmadjakusumah
Marion E. Betar
William L. Bitner
Addie D. Braydon
Kenneth N. Burdo
Bernice C. Bush
Everett Collins
John R. Dalton
William Fisher
Patricia S. Flood
Mildred B. Ford
Philip J. Fragassi
Robert L. Horton
Elizabeth M. Houghton
Malcolm F. Kelley
Viola B. Kelley
Geraldine Kenyon
Robert N. King
Robert C. R. MacFarlane
Donald McIntyre
M. Eileen McNamara
Janice Mahan
Barbara L. Martin
Elizabeth K. Montgomery
Estella Morse
Ruth Murray
Mary A. Y. Onisk
Florence V. Oths
Armand H. Pagliaro
Martha A. Park
Charles D. Potter
John B. Potter
Elizabeth W. Reed
Jacquelyn A. Russo
R. H. Situmeang
Clyde E. Smith
Viola L. Smith
William Stewart
Joan Ann Wescott
Judith A. Wolf

June E. Lewis
Irene C. Potter

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Elementary Science: An Overview

This science book is written for preservice and in-service teachers. It is also a book for educators who are working either with teachers or with children. The book is multipurpose in intent and aims to:

1. Name the specific process skills of critical thinking which can be identified and taught;
2. Show how to use the process skills to make critical inquiries;
3. Provide opportunities for imaginative thinking;
4. So direct inquiries in science that desirable attitudes will be developed;
5. Provide science content information;
6. Suggest worthwhile science experiences;
7. Design the type of experiments which are open-ended;
8. Provide opportunities for the acquisition of science facts;
9. Show how science generalizations are developed;
10. Show the value of excitement and enthusiasm in science discovery;
11. Encourage the development of well balanced science programs;
12. Make science a fundamental part of every elementary school curriculum;
13. Draw a pattern for a good science program;
14. Organize inquiries into sequences which grow in both depth and scope;
15. Help both teachers and pupils to evaluate what they have accomplished;
16. Help teachers direct the teaching of science toward the goals of education.

Organization

This book is divided into two parts. Part One deals with science education. It emphasizes that science is both *a body of organized knowledge* and *a way of thinking, working, and reacting* and that good science education is concerned with both. From both these aspects of science, students develop *attitudes* about themselves and the *nature and use* of their biological and physical environment. Part One discusses this dual nature of science teaching. Teaching science is *helping pupils inquire into the extensive body of scientific knowledge for understanding and literacy.* Good science also is concerned *with the methods by which understandings and literacy are attained* and *with the formation of desirable attitudes.* Pupils should have repeated opportunities to practice and use the skills which are basic to the process of scientific discovery and critical thinking.

Part Two of this book is organized around hundreds of *inquiries* which are interesting and exciting to students. The inquiries explore large areas of science. These areas are:

- The earth's rocky crust;
- The earth's atmosphere;
- The composition of things;
- Likenesses and differences between plants and animals;
- Forces and energy;
- The universe;
- Space exploration;
- Time, dates, and seasons around the world;
- Light and vision;
- The electromagnetic spectrum;
- Radio and television;
- Plants around the world;
- Animals around the world.

Part Two of the book has been extended in depth and scope. This has been done to help those elementary schools which:

1. Have a kindergarten-through-eighth grade program;
2. Are looking for new and challenging material to supplement science programs already well established;
3. Need more difficult inquiries for those pupils, or groups of students, who are ready and able to solve them.

Most of the chapters in Part Two are developed as *resource units.* Some, however, have been skeletonized into *reference chapters* in order to provide opportunities for preservice teachers to develop their own resource units. In-service teachers and pupils will be challenged by the same opportunities to develop and direct their own inquiries.

At the end of each resource chapter, there is a *summary of scientific findings* which the pupils are expected to *discover* during their investigations. Also, on the front and back end papers, there are four *chapter summary charts of process skills.* Check marks on the chart identify the process skills that can be developed. The teacher can make similar charts for recording the process skills his students have practiced.

Teachers should be aware that often it may be advisable to emphasize certain process skills. Whenever pupils need more experience with one specific process skill, the needed stress can be obtained by simply redirecting the emphasis of an activity toward the skill desired. For example, if the skill of predicting needs to be emphasized, it would be necessary only to ask, "Guess." or "What do you think would happen if. . . ?"

Each chapter is organized into a number of inquiries, arranged in sequential order from simple ones to more complex ones. The first inquiries in many chapters are very simple and are suitable for kindergarten and first grade children. As the chapter progresses, the inquiries become increasingly more complex, because the development is based on the assumption that the pupils have answered the previous questions. This is a sequential arrangement of inquiries.

Each chapter is presented in a series of inquiries stated as questions. The inquiries are stated not in the vocabulary of children, but as the teacher would interpret their questions. When children open an area for inquiry, they may not have the scientific vocabulary necessary to state the question fully. One group of children asked these questions about their locality:

1. How come there are shells in the rocks at the cement quarry?
2. Why are the rocks in the quarry slanted?
3. How did the sand get on top of the quarry rocks?
4. Why is it a different color?

Another group asked these questions about the place where they lived:

1. Why don't we have volcanoes like Hawaii?
2. Is our Mount __________ a volcano? It looks like one. Will it erupt?
3. How did so many mountains get here?

Both teachers interpreted these two separate series of questions as this inquiry: *What major changes have occurred to the earth's surface in the past?* Although the children's questions in the two examples were very specific, they definitely led into this inquiry as stated in the resource material in Part Two. Because children's questions can be so different and yet involve the same area of knowledge, listing the inquiries in this form seemed more practical. Later chapters point out in more detail that, after children have answered their original questions, it is useful for them to reevaluate and restate the questions. With their new vocabulary and knowledge, they should be able to combine their original series of questions into a large inquiry, much as it is stated in Part Two. Such restatement of questions and inquiries also helps children to summarize and clarify what they have learned.

The inquiry questions in each resource chapter of Part Two are numbered and arranged sequentially so that their investigation will lead children from a simple to a more advanced level of inquiry. The section that follows each numbered inquiry contains science background information and selected suggestions for activities, experiments, and *methods of practicing and teaching the process skills of critical inquiry.*

One or more ways to investigate the inquiries are given for the benefit of those teachers who want suggestions. Teachers should *feel free to select those inquiries they consider most suitable for their pupils.* They, also, should *feel free to select the methods and subject matter they consider essential for guiding pupils in their search for answers.* In addition, it is hoped that teachers and children will *feel free to make inquiries different from those in the book and to try their own methods for carrying out investigations.*

For pupils to propose the science inquiries and to plan and carry out their own methods of inquiry is ideal. This is not always possible nor is it always practical; therefore, some processes of discovery that pupils can use have been suggested for the teacher.

All the processes of discovery are intended to be open-ended. They will be if they:

1. Are suitable;
2. Emphasize that pupils participate in planning and selecting the processes of discovery;
3. Are investigated personally by the pupils;
4. Challenge pupils to make further inquiries and investigations;
5. Lead to an awareness of some of the many existing unknowns in scientific knowledge and prompt pupils to try imaginative thinking in a personal attempt to investigate and discover.

Several criteria were used for selecting the inquiries: (1) How important and challenging are the inquiries to children? (2) Do the inquiries increase the depth and scope of a pupil's understanding? (3) How important are they to the education of pupils everywhere in the world? (4) Which process skills do they provide opportunities for pupils to acquire and use? Do the inquiries challenge pupils to think critically and imaginatively? Can pupils be expected to develop worthwhile attitudes from the experiences?

Elementary school teachers have tested and pretaught most of the inquiries in this book. They have reported that the inquiries were interesting, important, timely, and challenging. Their reactions to the depth and scope of the material have indicated that their pupils were ready for this material.

The material we have presented in the five chapters in the section titled *Radio and Television* has not ordinarily been recommended for elementary school pupils. The findings of one piece of research done for a doctoral dissertation provide evidence that this area of scientific knowledge is challenging to children. It states that all children indicated an interest in all phases of astrophysical science, earth sciences, the ocean, animal life, and *particularly in television, radio, and radar.*[1] Before making a final decision not to use these chapters, we would recommend that teachers read them carefully and, if possible, personally try some of the experiments. They should then think about these questions:

1. Can I use some or most of the inquiries in these chapters with my pupils?

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[1] Abstract of an unpublished doctoral dissertation in *Research in the Teaching of Science,* U.S. Dept. of Health, Education, and Welfare (Analysis of Abstracts: 1959–61; studies completed: 1959–63); Genevieve G. Alford, "*An Analysis of Science Interests of Selected Children and an Identification of Problems Encountered by the Teachers of these Children in Science Instruction,*" University of North Carolina, 1959.

2. **Should I find out whether or not my class is more in tune with the science areas in these chapters than I realize?**
3. **Do I have individual pupils who would be stimulated by these chapters?**

Areas of science such as chemistry, physics, geology, and with a few exceptions, astronomy are traditionally treated in a framework suitable for pupils who live anywhere in the world. However, seasonal change, in the area of astronomy, is usually treated in a framework suitable only for pupils who live in the north temperate zone. This is also true in traditional studies of the effects of seasonal change on living things and the known and unknown reasons for their distribution on earth. *This book treats inquiries in these areas from a world point of view.* Do you and your pupils live in Florida or California, in Alaska or Hawaii, in England, Canada, or Australia? In this book you can find experiences illustrating the specific character of your seasons, whatever they may be, and the adjustments your plants and animals make to them.

How to use the book

No attempt has been made in the book to grade place any of the inquiries, process skills, experiences, or scientific findings it contains. Because of the variables in children's interests and abilities and because of the ever increasing knowledgeableness of today's children, we believe each school system should make its own decision for grade placement.

At present, grade placement of content, both in local and state science courses of study and in science textbook series, is based upon the judgment of experienced classroom teachers and science educators. Analysis of these publications shows variations of as much as three grade levels in the development of science understandings in some areas. This variation indicates that some educators believe that children can study more science at a younger age than was previously thought possible or practical. If science is taught earlier, more advanced material is needed in order to challenge elementary school children who are older, faster learners or more interested in science.

In Part Two, the inquiries, experiences, and scientific findings in each area sequence are extended in depth and scope to help teachers provide this challenge. Teachers who try to provide each child with opportunities to make science inquiries that have real meaning and challenge for him will find inquiries suitable for each child, whether he be a tortoise or a hare.

Over a period of time, the readiness of children to develop certain science understandings varies. This readiness changes as new science discoveries and inventions become a part of a child's world. A few years ago, seven- and eight-year-olds were playing Indians and cowboys. Today, although we still have Indians and cowboys, more and more children are weightless spacemen on the moon, who fire make-believe atomic guns. Some children are ready and eager to learn about such chemical and physical phenomena as the structure of atoms and molecules, nuclear energy, and space travel. These children need carefully selected experiences that will help them to develop correct understandings about these phenomena.

Many variables affect children's readiness for learning. Some of these variables are individual differences among children, differences in classes and groups of children from year to year, regional differences, cultural differences, and differences produced by recent scientific discoveries and inventions. These differences make it unwise to try to lay out a grade-by-grade sequence of science experiences and understandings that would meet the needs of all schools. Even a minimum, based upon what experiences teachers have found their children can understand, might be either too easy or too difficult for the same grade level under different conditions.

Nevertheless, because we believe that teachers need and want some direction in developing science experiences and learnings, we have organized each chapter in a sequence of inquiries. This sequence may begin with simple experiences, suitable for the primary grades, and build to more complex ones, suitable for higher grades and the more capable groups or individuals. The sequences of experiences, processes, skills, and findings in the resource areas may be used to select the process skills and experiences around which (1) a good local school program can be built; (2) a good classroom program can be based; (3) an enriched program for the pursuit of excellence can be structured.

In addition to the help these sequences provide for teachers and administrators in program building, they also provide help for (1) in-service teachers who feel a need to increase their own skill and confidence in teaching science; and (2) preservice teachers who wish to learn what science content, experiences, process skills, and understandings can be used with elementary school children.

What is a concept?

The word concept will not be used often in this book. We prefer to use such terms as science facts, learnings, understandings, and generalizations. Concepts are the means by which one interprets present experiences in the light of past experiences. All concepts develop gradually. A beginning concept may be nothing more than an interpretation of a scientific fact. After examining and playing with a magnet, a young child may say, "This is a magnet. Nails stick to it." It is his concept of a magnet. It will continue to be his concept until he formulates a more complex one based upon further experience with magnets.

There should be a time for children to discuss their science experiences. This will help the children to clarify their thinking, and help the teacher to evaluate the concepts the children are forming. Too little knowledge or too limited experiences may lead to the formation of misconceptions. Misconceptions are less likely to develop if children have opportunities to discuss and summarize their experiences. Some young children are very concerned about death, for example, and spend considerable time discussing it with their friends. A group of nine-year-olds had been reading about carbon dioxide. Their textbook said that carbon dioxide was used to put out fires. From an earlier lesson, the children had learned that their energy comes from the oxidation of food. The word *oxidation* had been used in the text, but the children did not know what the word meant. Their teacher told them that oxidation meant *burning*. But to them burning meant a fire with real flames. When the children combined the fact that "carbon dioxide puts out fires" with the erroneous concept "a fire in our bodies burns food," and interpreted the following experience in the light of their misunderstanding, they developed a frightening new concept. They stopped at a friend's house for a coke. While they were drinking it, one child said, "My daddy says these are carbon dioxide bubbles." Another said, "Then we'll be dead."

A concept may be simple or complex, depending upon the number and kind of related experiences and the abilities of the children to interpret them. Concepts are revised and expanded as the child gains meaningful experiences. This does not mean that a younger child with fewer experiences may not use the same words to express his concept as an older child with more experience. The mental images or the implications, however, are likely to be quite different. Both a five-year-old and a 12-year-old may say, "That rock is very old!" The younger child's concept of old would probably vary considerably from the older child's. Some kindergarten children were looking at a rock that one of the boys had brought to school. In answer to their specific questions and in order to help them build a concept of time, their teacher had told them that the rock was older than they; older than their mothers and fathers; and, yes, older than their grandparents. One persistent child asked, "Is it older than you?" "It certainly is." "What an old rock!"

A concept may be defined as an interpretation or understanding of what has been experienced. The concept may be an understanding of a fact, a scientific principle, or a series of related principles. A child's depth of understanding about himself, about other people, and about his universe depends upon the concepts he forms as a result of his experiences and upon his ability to interpret them.

The learnings and scientific findings in the chapter summaries of each chapter in Part Two are statements that children in different age groups have made in summarizing their experiences. Teachers need to be aware that each child in the room may have formed a different concept from the same learning. Some children have formed meaningful concepts; others may have formed inadequate or erroneous concepts. The teacher may use evaluation techniques like those suggested in Table 4.1 and 4.3 to help find out which children are ready to go on to further experiences and which children need to repeat the same experiences or have additional ones in order to develop the correct interpretations.

Children need correct vocabulary

Understanding the meaning of words is essential. In one situation, a word may have one meaning; in a second situation, it may have an entirely different meaning. A class of third-graders was identifying the different kinds of materials a goldfinch used in nest building. The children had identified all but one of the materials in the nest. The unidentified material had been used to line the inside of the bird's nest. The teacher said, "That material is cattail down. Doesn't it make a nice soft lining for baby birds? Try to imagine how many trips the goldfinch had to make to carry all of this down for the nest. What does the down feel like to you?" "Baby hair." Another child looked more and more unhappy as he pulled the down apart. Finally he blurted out, "Is this from a cat's tail? Gosh, that cat must have howled." Another teacher was puzzled by a child talking about a "coat" tree, until he realized the child was referring to the fir tree he had seen on a field trip the day before.

Sometimes elementary textbooks express ideas in words that children use in a very different sense than adults do. The teacher must take time to help children learn to understand the meaning of the word as it is used in a particular situation. What does the author of a textbook mean when he describes the generating of electricity, as a process of inducing or causing electricity to flow by "cutting" the lines of force in the magnetic field that surrounds a magnet? Does the author mean that the lines of force are cut into pieces? Does the rotating magnet actually have a "scissor or knifelike action" on these lines of force? When a teacher uses the word *organ*, does she make sure that some child in the room is not visualizing an organ as something that makes church music? These are not farfetched illustrations of the kinds of images words may convey to children. Every classroom teacher has a repertoire of similar illustrations that indicates the importance of developing a meaningful vocabulary as a part of the learning process.

If children can delve into science content that contains new words, they also can understand the meanings of these words. The teacher's attempt to substitute a supposedly simpler word may result in the formation of incorrect concepts. The anecdote cited earlier showed how a teacher who substituted *burning* for *oxidation* made one child think that coke might be a lethal drink. Children like big words; they are not afraid of them. Frequently no other word can be substituted for the correct scientific term. An important part of a child's science education is learning how to express his idea in words that are meaningful not only to children but also to other people with whom he communicates.

Part One

Chapter One

Teaching Science in the Elementary School

The Role of the Elementary School Educator

Elementary science is an integral part of both self-realization and citizenship education. It is essential for all children, if it is directed toward the *goals of science teaching*. It will help pupils (1) to intelligently understand and use the biological and physical environment; (2) to develop the insights and to cultivate the kinds of attitudes by which citizens respond and react to a society where almost every facet of existence is affected by scientific discoveries and inventions; and (3) to acquire and use the process skills of critical thinking.

Acquiring the process skills provides an opportunity for pupils to do imaginative thinking in the field of science as well as in other fields of knowledge, such as the arts, music, and social studies. Creative or imaginative thinking is a more complex form of thinking than the kind of critical thinking used in problem solving. Before creative thinking can occur, children must have some basic understanding of the various fields of knowledge that are involved. They also must be given the freedom to develop and to respect their intuitions and insights.

Inquiries into the various fields of science can help children develop the skills and attitudes essential for problem solving. It also can help them to think critically and creatively. To develop these two forms of thinking, they need help. They need the help of such educators as the administrator, the elementary science consultant, the science teacher, and the classroom teacher. The effectiveness with which pupils learn to think both critically and creatively depends upon how well educators understand, accept, and fulfill their roles. It also depends upon how well educators evaluate the results of their work and take the action necessary for improvement, and upon how well the teacher does critical, creative, and imaginative thinking.

The role of administrators

Elementary school administrators should understand the essentials in a good elementary science program. It is also their responsibility to provide opportunities for their teachers to master those essentials. Part One of this book can help both administrators and teachers to form these understandings. Part One also indicates the cooperative role administrators must play in providing teaching materials, methods of record keeping, ways for evaluating the program, and in-service help to teachers.

Part Two can be used to provide in-service help to individual teachers or to launch teachers into a curriculum study with the purpose of planning a dynamic science program containing a sequence of science inquiries, experiences, and learnings. Changing times, increased interest, greater emphasis, and teacher and pupil growth in the skill of problem-solving techniques are among the factors that schools must recognize as elements that will motivate and cause them to revise their elementary school science program constantly. Therefore, administrators should encourage their teachers to set up a tentative program, to test the program with children, and to develop it in a form that can be changed and revised easily and economically.

The roles of the science consultant

A science consultant (supervisor or coordinator) has a broad background in science and science education. In an elementary school system that has a consultant, he assumes the specific responsibilities for administering the science program which are described in the foregoing section. One role of a science consultant is as leader of a team of administrators and teachers that is responsible for developing a science program.

In addition to providing administrative leadership, the consultant is the leader of a second team of classroom teachers and children that is responsible for carrying out the program. In this dual role, the experience of each team improves the efficiency of the other.

The classroom teacher continues to assume major responsibilities for providing the opportunities for pupils to develop and to practice the process skills involved in critical thinking (problem solving). He also helps children acquire the basic science facts essential for understanding their environment, and at the same time, has the counsel, leadership, and experience of the consultant at his disposal. Classroom teachers use the consultant when they want specific help:

1. In program planning;
2. With experiences and science content to use with their children;
3. With those unexpected science inquiries which children constantly introduce;
4. With resource materials;
5. In working with children.

The role of the special elementary science teacher

A science teacher should have the same broad background in science and science education as the consultant. Science teachers work in two different kinds of setups. In one, the children come to the science room to work with the science teacher. In the other, the science teacher goes to the classroom to work with the children.

The science teacher's responsibility usually is limited to the children with whom he works. Commonly the program is outlined and controlled by the administrator. There are, however, variations of these plans. In some cases, the classroom teacher maintains some responsibility for the science program and the science teacher is given some administrative leadership in the development of the program.

The role of preservice teachers

It is the responsibility of preservice teachers who plan to teach in the elementary school to obtain as broad a background in science as possible. They should have some experiences and training in all science areas. It is also the preservice teachers' responsibility to find as many opportunities as possible to observe children of all ages working with science and to teach on as many grade levels as possible. By so doing, preservice teachers will gain a better understanding of the scope of the science program and of the ability of children to develop science concepts. Part Two of this book contains illustrations of what their role in working with children in science will be when they become in-service teachers.

Another role of preservice teachers is to prepare for the responsibility they will have in curriculum building for their grade, school, or school system. Curriculum resource materials consisting of sequential inquiries, experiences, and learnings can be found in Part Two. These sequences will help preservice teachers prepare for this role. Preservice teachers also should have opportunities to make decisions about the tentative grade placement of science learnings, to test these decisions with children, to compare their findings with textbooks and courses of study, and to discuss and evaluate their findings. During their discussions, they will find that there are differences of opinion about the grade placement of science learnings. Preservice teachers can thus become aware that children need a sequence of learnings in order to progress from one level of concept formation to the next, and become aware that a number of factors affect grade placement of learnings. The experience preservice teachers secure in their attempts to build a tentative grade-by-grade sequence of learnings will help them to understand the need for flexibility in grade placement of science content and to see the need for carrying on research of a similar nature when they become in-service teachers.

A third role of young teachers in both their cadet and in-service work is to bring new vitality and meaning to the elementary school science program. Many experienced teachers comment that these young teachers have inspired them to increase the depth and scope of their existing science programs and the use of problem-solving techniques.

The role of in-service teachers

The majority of elementary school systems depend upon teachers in self-contained classrooms to teach science. In this case it is the in-service teacher's responsibility to work with children in science just as it is his responsibility to work with children in other subjects. The teacher in the self-contained classroom has some of the same responsibilities as the administrator, the preservice classroom teacher, and the science teacher.

The in-service teacher's role is to:

1. Have as broad a background in science as possible;
2. Understand what constitutes a good science program;
3. Help children acquire and practice the process skills of critical thinking;
4. Help children explore science inquiries;
5. Help children develop science understandings and concepts;
6. Provide opportunities for children to develop their imaginations;
7. Help children cultivate intuitive thinking and recognize its importance;
8. Attempt to provide for children's individual differences;
9. Carry on research;
10. Assist in curriculum building.

Accepting and preparing for the roles

Educators know that children ask questions about everything; children's questions probe into all areas of science. This widespread interest can be frightening to those who have a good science background and even more so to those who do not. A positive attitude toward this wide range of children's questions is characterized by such questions as: "How can I best help children with their science inquiries? Do I know enough science? Where can I study? Will I have in-service help?" Educators who have this attitude have some of the essential qualifications for their roles; i.e., they are ready and willing to try, to ask and accept help, to study and continue to study, to learn, and to improve.

Many have demonstrated that sincere pursuit of these qualifications has helped them gain the necessary science background and methods for truly effective science teaching in the elementary school. Many educators have demonstrated that through their sincere pursuit of these qualifications, they have gained the additional ones needed for carrying out a good elementary science program.

How teachers fulfill their roles

A child's curiosity is one of his most precious possessions. It is a manifestation of his zest for knowledge. It can be cultivated and developed by educators who encourage him, or it can be lost if it is suppressed. A young child asks questions freely. He has many science questions. He is curious about everything in his world. He isn't embarrassed about asking questions. Do teachers ask questions freely and let children know that they also are interested in learning about science? Teachers who are curious, or who will cultivate their curiosity, create in their classrooms a climate favorable for learning. Children are more stimulated by the teacher who is as curious about science as they are and who can find ways for them to *explore their own inquiries,* than they are by the teacher who knows and tells all the answers. Children don't want or need a teacher who is just a "textbook." What a teacher says and does and the way she acts make a deep impression on children. A teacher quickly wins the respect of children when he lets them know that he is willing to tackle with them science inquiries to which he does not yet know the answers. The *exploration of the inquiry* then becomes a cooperative venture.

A young *science teacher* had the following experience during his first year of teaching. His class was composed largely of boys who were eager to learn about science. In the same school there were two experienced science teachers to whom these boys had hoped to be assigned. This young teacher knew that he was being appraised by the class. The teacher's test came during a study of electric motors. The textbook gave an explanation of direct current motors, but it did not mention alternating current motors. When the class questioned him about the difference, he very wisely admitted that he did not know. He did not try to evade the question, however. Rather, he said he would try to find the answer if they would try also. He sought help from both of the other teachers. Unfortunately, their explanations did not help him understand the difference. He did realize, however, that, until he understood the difference between the two types of motors, he could not help his class *explore the inquiry*. He also knew that the children would be aware of his uncertainty.

The *inquiry* about alternating versus direct current motors challenged both the teacher and his pupils. Both sought information from many different sources. The father of one of the boys was an electrician. He tried to explain the difference to his son. The boy could not understand his father's explanation well enough to help his classmates. Under the barrage of his son's questions, the father admitted that he could not phrase the explanation in nontechnical language. The next day, father and son came to class carrying a one-half horsepower, alternating current motor. The father said, "Here's a motor. Take it apart. Find out what you want to know. Don't worry if you can't put the motor together again. I'll do that."

The teacher helped the class take the motor apart. This experience provided the answer. They drew large comparative diagrams of both motors on the chalkboard and indicated the difference between these motors with colored chalk. They proudly showed and explained these diagrams to all their friends and to all the people who had tried to help them. Both the class and the teacher experienced such satisfaction from their cooperative effort that the "climate for learning" in this classroom remained high all the rest of the year.

It is just as important to be able to say, "I don't know," to a first grade child as it is to an older child. A group of first-graders were working on the learning: Fire needs air to burn. They had done many experiments. During their discussion period, they asked, "Why is water used to put out fires?" Their previous experiences prompted some children to reply, "The water covers the fire so it can't get air. Fire goes out when it can't get air." One child thoughtfully said, "Water's cold. Cold does it." This was a new idea to the teacher as well as to the children. They discussed the new idea and decided to try to find whether "cold" makes the fire go out. How to prove whether the idea was right or not was as much a problem to the teacher as it was to the children. At the moment, he could not even think of any way to help them find their answer. However, he did not dismiss the question as unimportant. He needed time to consider what the next step should be. Because none of the books in his room provided the information for which he was looking, he decided to ask the high school science teacher for help. He reviewed the children's experiences that had produced this poser and then said, "I don't know the answer so I came to you for help. I think the inquiry is a valid one and I'd like to help my children explore it. You realize that I must understand the solution before I can help six-year-olds to comprehend it."

This is the information which he received from the science teacher: Different materials ignite at different temperatures. The temperature at which a fuel burns is called the *kindling temperature* or the *ignition point.* If you put a piece of paper, wood shavings, and a piece of coal on a hot stove, they will ignite at different times. The paper will burn first because it has the lowest kindling temperature. When a coal fire is started, the heat of a match flame heats the paper to its kindling temperature. The burning paper heats the kindling wood to a temperature at which it ignites; and the kindling wood, in turn, heats the coal until it is hot enough to burn. The temperature of water, even water boiling at 212°F., is less than the kindling temperature of paper. If you place about 1 inch of water in a paper cup and hold this cup and an empty paper cup over a source of heat, such as a candle flame or an alcohol lamp, the cup without water will quickly ignite, but the one with water will not burn even when the water boils. (When you try this, better have a pan of water ready in which you can drop the flaming cup.) Both cups are exposed to the same amount of air and the bottoms of the cups are exposed to the same amount of heat. However, one cup has water in it. The water prevents the temperature of the bottom of this paper cup from rising above the boiling point of water. Because the kindling temperature of paper is higher than the boiling point of water, the paper containing the water is too cool to burn.

The science teacher, to whom the classroom teacher went for help, was stimulated by the classroom teacher's account of this question which had been raised by his six-year-olds. He gave his information clearly and simply even though he gave it on an adult level. He realized that this teacher was as much of a specialist in dealing with six-year-olds as he was a specialist in science. The teaching profession is composed of many different kinds of specialists. He complimented the teacher when he said, "I can give you the facts; but I don't know enough about little children, or about the elementary science program, to tell you how to use these facts. Would you let me observe when you help your class explore this inquiry?"

Thus did one teacher learn that each question asked by a child or class deserves consideration. This teacher did not evade or minimize the importance of the question and thus discourage the child. The teacher did not lose prestige by seeking information, but gained, instead, the respect and admiration of both the children and the high school science teacher.

Suggestions for the teacher's "solo flight" in science teaching

For teachers who are going to teach science for the first time, some of these suggestions may be helpful.

Select an Inquiry of Enough Interest to You So You Will Enjoy Teaching It. There are many large science areas developed in Part Two of this book that should interest both the teacher and the children. Match the children's questions to similar inquiries. Use the experiences to help the pupils. Check their findings with the summary list of scientific findings at the end of the chapter. Concentrate on the content involved in one area. Use all other available related resources for information and experiences to supplement the material in this book.

Plan and Work for Success; Next, Look for Ways to Turn Any Failure to Your Advantage. The continued interest and success in working with children in science depends upon the satisfaction experienced in science teaching. Therefore, make the selection of a science inquiry balance with these factors: teacher interest, pupil interest, pupil maturity, teacher ability, and pupil ability. If science inquiries are chosen and developed with enthusiasm, the children's responses are more likely to be enthusiastic. Enthusiastic responses from children will give the feeling that the efforts are really worthwhile. Such an experience will help to develop confidence. As confidence and ability continue to grow, try providing experiences in other areas of science.

There will be occasions when the teacher and the children feel that a particular activity, experience, or experiment has failed. Remember that scientists, too, have similar frustrations and that, in many instances, these very failures motivate them to the kind of experimentation that leads to success. In the classroom, the teacher and the children also can look for ways to turn failure into success. Failure can often lead to a learning situation that is very challenging and worthwhile.

Experienced teachers have learned how difficult it is to rebuild a child's feeling of confidence and satisfaction after failure. When this happens, feelings of inferiority must be replaced with self-confidence before this child can again obtain the feelings of satisfaction that motivate continued effort. Steady progress, stimulated by success, is of major importance to children. This same criterion applies to the teacher's science work with children.

Share Your Success with Your Colleagues. Invite other classes to the room to see and hear what the children are doing in science. Visit them for the same purpose. Share successful experiences with colleagues and encourage them to share theirs.

Keep a Science File. This file should contain the activities, experiences, and learnings used in each inquiry. Organize a file exchange with other teachers in the school system. This kind of an exchange system, in addition to helping the teacher enlarge the number and quality of the experiences which can be planned for children, will also help to build a well-balanced science program in the classroom much more rapidly than can be done alone.

Keep a File of Community Resources. Make an inventory of the resources in your community that can be used for field trips. Field trips are rich sources of firsthand experiences for children. Every community has some of the following resources: commercial industries, gardens, parks, museums, zoos; and such municipal plants as hospitals, water purification, sewage disposal; and county, state, and federal bird sanctuaries. Visit these places and find out whether: 1) children are welcome, 2) the trip is worth the time and effort, 3) fees are charged, and 4) transportation is necessary.

Keep a record of these resources and utilize as many of them as practical. A field trip can be taken at any time during a unit of study; however, the best time is probably the middle part of the study when there is time to investigate further for new information.

Also utilize such specialists in the community as a photographer, the high school and college science teacher, the county agricultural agent, hobbyist, and members of clubs pursuing various science-related interests.

Observe Other Teachers. Observation is very helpful. A few periods of observation will show that the same techniques used in teaching other subjects are also used in good science teaching. By observing other teachers, a classroom teacher can learn how to help children make discoveries in science.

Enroll in Science Courses. Many science courses may be offered in the community. Many universities and colleges offer summer and extension courses or workshops in science for teachers. Some of these courses are designed to give experiences in special fields of science.

Evaluating science teaching

Every conscientious teacher wants to know how to evaluate the effectiveness of his teaching. Good science teaching is going on in your classroom:

When your children ask questions that cause both you and them to examine the inquiry in a new light;
When children provide evidences that they are doing critical thinking;
When children are not embarrassed when their educated guesses or their answers to questions are wrong;
When there are desirable changes in the children's behavior patterns, which can be attributed to their science experiences;
When it is necessary to go beyond the walls of the classroom to get assistance from your community;
When the classroom looks like a workshop in which both individual children and groups of children are eager to get back to work on their science projects;
When the teacher gives the children the time, the space, and the encouragement to contemplate;
When all children are not required to work on the same inquiry and participate in the same number and kinds of experience.

Evaluating the school program

Teachers and administrators can evaluate the effectiveness of the whole science program. The school has a challenging, worthwhile science program:

When a variety of firsthand experiences are used to help children develop meaningful concepts;
When science understandings are applied in other areas of the curriculum;
When children and teachers use *community resources* to help them;
When the taxpayers and industries in the community offer their resources;
When the community and the school recognize the need for a good science program and provide adequate financial support for it;
When the science curriculum is being revised in order to update it;
When teachers and administrators do not underestimate children's abilities to develop concepts that were formerly considered too difficult for them;
When evaluation shows evidence of growth in the depth and scope of the total science program, growth in teaching skills, and growth in abilities, understandings, and attitudes of children.

ADDITIONAL READING

Association For Childhood Education International, *Science for the Eights-to-Twelves,* Membership Service Bulletin No. 13-A. Washington, D.C., 1964–65.

Association For Childhood Education International, *Young Children and Science,* Membership Service Bulletin No. 12-A. Washington, D.C., 1964–65.

Gruver, William J. and Albert Piltz, *Modern Science and Your Child,* U.S. Dept. of Health, Education, and Welfare, Office of Education. Washington, D.C.: Government Printing Office, 1963.

Tannenbaum, Harold E. and Nathan Stillman, in collaboration with Albert Piltz, *Evaluation in the Elementary School,* U.S. Dept. of Health, Education, and Welfare, Office of Education. Washington, D.C.: Government Printing Office, 1964.

Chapter Two

Goals of Science Teaching

All education, including science education, strives to achieve three major goals. It is believed that through (1) *the practice of the process skills of critical inquiry* and (2) *the acquisition of facts, understandings, and concepts* (3) *desirable attitudes and worthwhile pupil behavior* will be developed. Actually, the development of desirable attitudes is the ultimate goal of education.

The ability to think critically requires a number of skills. The Commission on Science Education of the American Association for the Advancement of Science has analyzed the processes of critical inquiry and has defined these specific *process skills* as ones that can be identified and taught.[1]

1. **Observing**
2. **Classifying**
3. **Measuring**
4. **Recognizing space-time relationships**
5. **Recognizing number relationships**
6. **Communicating**
7. **Inferring**
8. **Predicting**
9. **Formulating hypotheses**
10. **Making operational definitions**
11. **Controlling and manipulating variables**
12. **Experimenting**
13. **Interpreting data**
14. **Formulating models**

Because the field of science offers pupils so many opportunities for making progress toward the three major goals and for practicing the fourteen process skills, science should be an important part of the elementary school curriculum for *all children,* whatever their abilities, hopes, or ambitions.

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[1] Arthur H. Livermore, "The Process Approach of the AAAS Commission on Science Education," *Journal of Research in Science Teaching,* (1964), II, 271–82.

Observe in the following excerpts that the American Association for the Advancement of Science, the Association for Childhood Education International, and the United States Department of Health, Education, and Welfare also recognize the same goals for science teaching.

Teachers and children of today need an abundance of knowledge about the achievements of science and mathematics.[2] Even more, they need to acquire the *seeking, questioning attitude* of mind, and the *habit and skills of clear honest thinking* which characterize the scientist as he seeks further knowledge.

They also need to *practice* and *recognize the value* of sheer *imaginative thinking.* They need to think, to dream far and wide, to think up way-out ideas that may one day be reality in science discovery. Scientists know the value of such imaginative thinking and practice it as a means of reaching beyond that which is logically obvious and tangible.

The pupil who learns science learns *more than a set of facts* about the world of objects and living beings. He also learns *ways of finding out about the world* and *ways of ordering his findings.* He finds *ways of asking questions* and *ways of getting answers.* He learns, too, that his answers, like those of the adult scientist, *are partial, and tentative* and *that scientific inquiry is not magic but an exciting and active approach to knowledge.* The child *who learns science as inquiry* will be *inquisitive, skeptical,* and *alive to the world in which he lives.* The teaching of science in its best achievement, will help the young child develop *knowledge of the concepts of science, skills in methods of science,* and *enthusiasm for scientific inquiry.*

Attention must be directed toward two aspects of the science program, (1) the *dimensions of knowledge or content* and (2) the *dimensions of performance or process.*

To be effective, each dimension must become the vehicle for the development of the other. A student will use the study of subject matter as a means for the development of skills and abilities; and his skills and abilities will also be a means by which he increases his knowledge of subject matter.

An appreciation of the esthetic aspects of science and mathematics should develop through individual discoveries and experiences. This is of considerable importance in inducing favorable attitudes toward science and mathematics, and hence in accelerating the learning process. The child should learn to appreciate that science and mathematics are living, dynamic, creative, and changing human endeavors.

The role of mathematics in science is certain to be intensified, and an early awareness of it as a study of the structure (order), relation, and form of science should be developed by the elementary school age child.

The effect of the proper teaching of science should be evident in the *mental and physical reactions* of pupils. Such qualities as *resourcefulness, responsibleness,* and *creativeness* should be characteristics of pupils who are receiving proper guidance in elementary science. Science teaching should be oriented to inquiry and should foster children's diligent search for explanations of observable and unobservable phenomena. Science should employ the methods of learning that have built the present extensive body of scientific knowledge.[3]

Science for the elementary school child begins with *curiosity* about the *total environment.* And the total environment is *extensive.* Not just the near at hand but the entire universe can and should be investigated.[4] If science is properly taught, it will develop a way of thinking, organizing, classifying, and working. It also will require that children learn to identify inquiries and to explore them. Because the problems which arise will be *inquiries* into the various fields of scientific knowledge, the pupils will *acquire understandings* of the basic principles of science and will *develop the skill of careful observation* and an *attitude of questioning and exploring.* Modern science teaching is most concerned with developing an inquiring mind, and respect for scholarship, for science is essentially a method of learning...not a book of answers.[5]

With proper guidance children can acquire desirable attitudes that should influence their actions as citizens. Among these attitudes are

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[2] Guidelines for Science and Mathematics in the Preparation Program of Elementary School Teachers, AAAS Misc. Publ. No. 63–7, NASDTEC-AAAS Studies, 1515 Massachusetts Ave., Washington, D.C. 20005.

[3] Association for Childhood Education International, *Science for the Eights-to-Twelves.* Membership Service Bulletin No. 13-A (Washington, D.C., 1964–65), p. 5.

[4] *Ibid.,* p. 5.

[5] U.S. Department of Health, Education and Welfare, *Modern Science and Your Child* (Washington, D.C.: Government Printing Office, 1963), p. 3.

(1) the questioning of vague explanations; (2) the rejection of gossip and superstition as valid explanations; (3) the awareness that all knowledge is tentative; (4) that man's conception of truth changes; (5) that much knowledge remains to be discovered.[6]

Science for children becomes discovery rather than memorization of facts. Instead of giving answers to children's questions and solutions to their problems, adults must provide opportunities which stimulate children *to find their own routes* to discovery. The teacher's role is one of encouraging children to speculate, to make intelligent guesses about answers to questions and solutions to problems.[7] Children must feel free to explain their ideas and to plan ways of trying or testing their hypotheses. If their ideas do not work out, children must feel no humiliation in failing.[8] It is a part of the teacher's role to help the child assess his results, interpret, and encourage him to try again.

The educated citizen of tomorrow who is today's school child will need a far better understanding of science and mathematics than most people now possess.[9] This is the reason why science teaching is most concerned with developing 1) an inquiring mind; 2) a basic understanding and use of the biological and physical environment; and 3) attitudes and process skills that are essential for literate, democratic citizens who will be able to actively participate in the decisions of their society. Society is faced with science-related problems, whose many facets will be resolved best by scientific explorations, discoveries, and inventions. Children live in a society that is based upon science. The influence of science and technology is reflected in their living habits, their comforts, their leisure-time enjoyments, and the careers which they will eventually enter.

Our world is changing with startling rapidity. Change is not a new force that has suddenly come into being. It is a natural phenomenon that has been occurring since the beginning of time. Scientific advancement, however, is constantly increasing the rate at which changes are occurring. Consequently it is more important today than ever before for children to receive the kind of education which will equip them to anticipate this acceleration, to obtain the know-how necessary to adjust to it, and to solve the problems which constant change creates.

From the fields of scientific knowledge, teachers may draw a variety of experiences to meet children's needs. Scientific experiences contribute much to child development. Children need the security and satisfaction that come from gaining understandings about themselves, about other living things, and about the natural forces of the universe.

For hundreds of years, man has tried to increase his knowledge of his environment. Man gazes at the heavens and attempts to interpret what he sees. By his diligence and genius, man employs techniques and develops instruments which enable him to certify or reject these interpretations. Man is learning to explore the depths of the seas. He is prying into the crust of the earth and creating instruments by which he hopes to discover its composition. He has already succeeded in tearing the minutiae of matter apart and has produced new elements which are not to be found in nature. Man is rapidly learning how to utilize natural resources better and how to modify living things to suit his purposes. He is even building and using rockets and satellites to extend his realm into space. Despite all this, there is still much that he does not know.

Boys and girls alike are fascinated by learning how much man has discovered during his comparatively short stay on this earth. They are excited and stimulated to action when they are given the opportunity to follow some of the same techniques that have enabled others in the past to make these wonderful discoveries. Their imagination is fired by the knowledge that great problems are still unsolved, and they are personally challenged to do something about them.

Science education capitalizes upon the sense of self-importance which is born in every child. It helps him to make use of this sense in order to benefit both himself and society. This self-importance must not be misdirected and used solely for selfish purposes. For the sake of all mankind, it must be nurtured, cherished, and so motivated that each child will grow up to assume his rightful share of responsibility for the welfare of society.

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[6] Association for Childhood Education International, *Science for the Eights-to-Twelves*, Membership Service Bulletin No. 13-A (Washington, D.C., 1964–65), p. 10.

[7] Association for Childhood Education International, *Young Children and Science*, Membership Service Bulletin No. 12-A (Washington, D.C., 1964–65), pp. 4–5.

[8] *Ibid.*, p. 5.

[9] NASDTEC-AAAS Studies, *Guidelines for Science and Mathematics in the Preparation of Elementary School Teachers*, AAAS Miscellaneous Publication Nos. 63–67, pp. iv–v.

As each inquiry progresses, the teacher must repeatedly decide whether or not:

1. Class interest and enthusiasm in the inquiry remains high;
2. The information being acquired is meaningful and pertinent;
3. The process skills are being used advantageously;
4. The children's behavior is reflecting their attitudes, especially any desirable changes in their attitudes.

In addition the teacher formulates *specific objectives* to serve as day-to-day guidelines for planning and teaching. The following descriptive record shows how one teacher directed a series of inquiries not only toward the major goals of science teaching but also toward the following list of specific objectives. Observe that the investigations increased in scope and that the methods provided increased opportunities to practice many of the process skills. Also observe that a number of opportunities occurred for the children to do imaginative thinking.

The teacher hoped that:

1. The pupils would develop the understanding that change, a cause and effect relationship, has been, is, and will continue to be a fundamental phenomenon;
2. The pupils would do both critical and imaginative thinking;
3. The pupils' understandings of themselves and their relationships to their environment would be increased;
4. The pupils' enthusiasm for seeking more and more knowledge would be retained;
5. The attitudes of all pupils would reflect their willingness to accept the responsibility that society needs their best talents and wisdom;
6. These inquiries would provide children with as many opportunities as possible to practice a maximum number of process skills.

An example of teaching directed toward the goals of science education

An incident like the following occurs many times in any classroom.[10] The *problem*, or the *inquiry*, this incident presents may not be new, but to this class of young children, it was new and exciting.

The class had been learning about plants and animals. One day, looking at some pictures of whales and elephants, they realized that these mammals appeared very large compared with white mice, which they had raised in their room. Since the question of relative size had been brought up, it was recognized as an inquiry for the class to explore. The children who owned dogs decided to measure the dogs to see who had the largest and who the smallest. Each child used a piece of string to find the length of his dog from the tip of his nose to the tip of his tail and then determined the number of inches in the string. The class discovered that John's dog was the largest and Susan's the smallest. The children also decided that they could use string to measure how tall different plants grow, and they measured the height of the plants on their classroom window sills. Someone asked, "How high is a tree?" This was solved a few days later when the city tree commission cut down a tree in the next block. Before the men could cut it up and take it away, the children took a trip to the spot with a ball of string and measured its length (height).

Another day, the children went to a nearby field to compare the size of insects. A butterfly and an ant were the largest and smallest insects they could find. You can imagine the teacher's reaction when the next morning one of the boys appeared, carrying a flea which he had gathered from his dog's fur. In order to see the flea clearly, the children used a magnifying glass.

After these experiences, the teacher helped the children make a careful summary of what they had learned. They decided that the plants and animals with which they had worked varied in size.

The Children Pose a New Inquiry. When the pupils made this conclusion, they seemed to be ready to dismiss the inquiry. One child then asked, "Are there any animals smaller than a flea?" The question reopened the whole matter of the size of living things. Before the question could be discussed, many comments and additional questions came from the children in rapid succession.

"What is the smallest animal?"
"What is a germ? Is it an animal?"
"We can't see germs, can we?"
"Maybe we could with a magnifying glass."
"I bet I could see it with the microscope in

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[10] This is an *actual problem-solving situation* that occurred in a third grade in a public school. Records and teacher judgment rated this class as average. Although the teacher's science background was only fair, he had a master teacher's ability to get children to think and to discuss their ideas and experiences.

my science kit. I can see things smaller than fleas. I'll bring it."

"Are there any tiny little plants?"

"Can we look for some?"

"Where would we look?"

The Children and Teacher Identify the New Inquiry. The original inquiry had now developed depth and scope, and the teacher realized he should help the children formulate the new question they wanted answered. This is what they decided to find out: *Are there living plants and animals so small that we need to use a microscope to see them? If there are, where can we find them?*

Children and Teacher Plan the Procedure. The teacher and each member of the class shared in the planning. In addition to the microscope one child had promised to lend, the teacher said a microprojector could be borrowed from the science supply room as well.

The children discussed where to get microscopic plants and animals, and decided to look for them in water, soil, and air, because they had learned that larger plants and animals lived in these places. The children organized themselves into three groups: one group agreed to collect samples of water; the second group, samples of soil; and the third group, samples of air.

The teacher helped the third group plan a way to collect the samples of air. They filled jars with water, put tight covers on them, and carried them to the places where they were to collect the samples of air. At the chosen place, they opened the jars and dumped the water. The water was replaced by air. The jars were sealed, brought back to the classroom, and labeled for future study.

The first group, which collected water samples, had done a very thorough job. They produced many bottles of water, each carefully labeled. They had samples from the canal, from the brook, from a mud puddle, from a puddle in a barnyard, and from the faucet. They took a few drops from each bottle and examined them with the aid of the microprojector. In four of the bottles, they saw things that moved. In the brook water, they also saw tiny, round, green things. The class decided that the things that were moving were live animals and that the green things must be plants. Although they examined many different samples of water from the faucet, they could find no animals or plants in them.

The Children's Attitudes Are Affected; the Need for Further Exploration Emerges. During the discussion of the first group's findings, the following significant statements were made:

"I wouldn't want to drink that canal water."

"I'm not going to swim in the canal!"

"I'll bet that's why my mother won't let me swim in the canal!"

"I'm glad that we didn't find any living things in the water we drink."

"Let's get some water from the lake. Maybe there are tiny living things in lake water too!"

"Maybe we shouldn't drink any water except city water."

The following additional questions were raised:

"Should we drink water from brooks?"

"How can we kill the living things that are in water?"

"When should we kill the living things that are in water?"

"When should we not do so?"

"Does the city do something to kill the living things in our drinking water?"

"How does the city do this?"

All these inquiries were explored before the children finally left this area of interest.

Judgment Is Suspended; the Children Remain Open-Minded. The second and third groups did not find their answers as easily as the first. The second reported that they could see pieces of soil through the microscope, but they could not see anything alive in it. The third group, looking through the microscope for living things in air, said, "When we opened the jars to put the air on the microscope slide, *we think* it mixed with the air in the room. We couldn't be sure what air we were looking at. We used the magnifying glass and looked in one of the bottles without opening it, but we couldn't see anything."

These two groups needed a new method of attack and asked, "Is there a better way we can use?"

The Children and Their Teacher Plan a Different Attack. As the children discussed other methods to use in exploring the inquiry, they applied a number of concepts formed in an earlier grade. One fact was very pertinent to the exploration of the inquiry: living things grow and reproduce. Remembering this, they reasoned that if there were living things in air and soil, it might be possible to grow enough of them so that they could be seen. This suggestion raised another question: "In what can we grow them?" Their teacher suggested that they borrow five petri dishes from the science supply room. When the children examined these covered glass dishes, they saw that nothing could get in or out of them unless the covers were removed. The petri dishes were something in which to grow the living animals or plants that might be in the samples of air and soil. The next question was: "What shall we use for food so that the tiny plants and animals will grow and reproduce?"

The Help of Authorities Is Sought. Someone suggested that the nurses who worked in the hospital might be able to help them. The teacher made an appointment for a committee of children to go with him to the hospital laboratory. Here they learned about the kind of food to put in the petri dishes. They also learned other interesting things.

When the committee returned, they told the class how the nurse boiled or *sterilized* the dishes to kill any "germs" (viruses and bacteria) that might be in them. They described how she poured a hot liquid that looked like lemon jello (really nutrient agar) into the petri dishes. When the liquid cooled, it thickened like jello, too! The nurse gave them the petri dishes filled with nutrient agar and told them that if they did collect any living things, the food in these dishes would "taste" as good to these tiny consumers as a turkey dinner would to the children. She cautioned them to keep the dishes closed until they were ready to use them.

Their Understandings Are Clarified. Following the committee's report, there was a lively discussion. The children discussed the meaning of the word *sterilize.* They reasoned this way: The way the nurse killed any living things on our dishes was just like boiling. She called this boiling, *sterilizing.* There is nothing living on the food in our dishes, now, because they have been sterilized. One child with a new baby brother used the word *sterilize* in a new situation when he said, "My mother must be sterilizing the baby's bottles because I've seen her boiling the bottles."

When a few children still did not understand why the nurse had sterilized the petri dishes and why sterilizing them killed anything that was in them, the group of children who had collected the water samples said that they thought they could use the microprojector to show the class that boiling will kill living things in brook water. They let the class look again at some brook water in which they saw tiny living things, which they thought might be animals because they were moving around very rapidly. They also saw tiny green things. Some of these green things were ribbon shaped; others were round. The teacher said that these tiny green things were plants. Then the children boiled some of the water. After the sample of brook water was boiled the pupils could see no sign of plant or animal life in it. The evidence supported the group's claim that *boiling sterilizes water.* Still another question was raised: *Does the city boil all the water that comes into our homes?* This inquiry was temporarily set aside until the children had explored the immediate inquiry upon which they were working.

The Children Try the New Method of Attack. The next day, the teacher showed the children how to open the first petri dish and expose it to the air for five minutes and then how to cover it again. The second dish was given to a child who was chewing his pencil. The teacher told him to open the dish and rub the pencil on it, and then close the dish very quickly. The children sprinkled a few grains of soil on the food in the third dish and covered that dish, too. The fourth dish was given to a child whose hands were dirty. He was directed by the teacher to open this dish, press his fingers on the food in the dish, and close it again. The fifth dish was not opened; it was to be a control.

The New Findings Are Evaluated. All five petri dishes were carefully labeled and put away in a warm place. Three days later, the children noticed that something seemed to be growing in the four dishes that had been opened, but they saw no evidence of change in the fifth, or "control," dish. The children examined the growths in the four dishes with a magnifying glass. They agreed that the things they saw must be living because living things grow and reproduce. They concluded that there are living things in air, in the soil, on pencils, and on their skin. They had already learned that living things may be present in water which has not been boiled. The only place they had not found them was in the water from the faucet.

The teacher invited the manager of the city

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water department, the manager of the YMCA, and the school doctor and nurse to talk with the children one afternoon. Each expert stressed a few simple ideas.

The manager of the city water department showed some colored slides, which helped the children find out how chlorine is added to the city's drinking water. He told them any disease-causing organisms in the water would be killed by the chlorine before the water could reach their homes. They asked him whether boiling would do the same thing. He agreed it would, but pointed out how difficult it would be to boil enough water for such a large city.

The manager of the YMCA, where the boys were learning to swim, came and explained why the club adds even more chlorine to the water in the swimming pool.

The school doctor stressed the reasons why the children should stay at home when they have a bad cold or are ill. He told them that not only would they get well faster at home but also they would not expose the rest of the class to their colds.

The school nurse brought tongue depressors, sterile gauze, and Band-Aids, and explained that these things had been sterilized and sealed so that, when she used them, there would be no disease-causing organisms on them. She also said soap was a fine thing with which to kill these kinds of living things and stressed the importance of having clean hands.

Then the nurse and doctor demonstrated how a nurse helps the doctor scrub and get into sterile rubber gloves, cap, mask, and gown. They had brought sterile gowns, masks, rubber gloves, and towels. They even had soap, brushes, and a basin, which they pretended was a lavatory. As closely as possible, they went through the complete scrubbing and gowning routine with appropriate dialogue to emphasize the many precautions taken to be sure the doctor would carry no disease-causing organisms into the operating room at the hospital.

Evaluating the children's experiences in terms of specific objectives

Did These Children Have Some Experiences with Changes that Occur in Their Environment? The children worked with a basic form of change: growth and reproduction. They learned that boiling or sterilizing kills the living organisms that may be present on objects. They learned that chlorine is added to their city water supply to kill living organisms that may be present in it. The children had opportunities to form beginning concepts regarding the waste disposal that is caused by community living and the need for community controls to prevent water pollution. The question of water pollution was not pursued very far by these children. Somewhere in the elementary grades, however, this concept should be broadened and deepened. Children need to be aware of undesirable changes like water pollution and to develop understandings that will promote effective action to control them.

Did the Children Grow in Their Ability to Think and to Act Wisely on the Basis of What They Learned?

A. The teacher helped the children explore meaningful inquiries like these:
   1. How small can living things be?
   2. How can we find out whether there are any living things so small that they cannot be seen without a microscope?
   3. How can we grow these tiny living things in our classroom?
   4. Why are many things sterilized?
   5. How can we kill the tiny living things present in brook water? Should we kill them?

B. The teacher helped the children practice these techniques:
   1. They demanded adequate evidence that microorganisms exist.
   2. They tested their hypothesis that living things are present in water from the aquarium, canal, barnyard puddle, and brook.
   3. They collected samples from many different sources in the process of finding out where microorganisms live.
   4. They were not satisfied with their findings regarding the absence of life in air and soil and formulated a new hypothesis and a different method of attack.
   5. They went to an authority to find out how to grow microorganisms.
   6. They were careful about their procedures in setting up the experiment in which they hoped to discover whether microorganisms were actually present in air and soil.

7. They boiled only part of the water from the sample of aquarium water and kept the other part for comparison.
8. They tried to limit the variables in their experiment by exposing each dish to a different source and by keeping one dish for a control. (They had reasoned that, if no organisms grew in the control dish, they would be almost certain that the organisms in the dishes, which had been exposed to different sources, came from the source of exposure.)

C. The teacher gave the children opportunities to develop desirable attitudes when he encouraged them:
   1. To follow through on the exploration even though their first attempts were only partially successful.
   2. To withhold judgment and keep open-minded, as evidenced by their refusal to accept the apparent absence of living things in their first experiments with samples of air and soil.
   3. To search for an alternative method for exploring the inquiries and plan a different attack.
   4. To seek assistance from an authoritative source.

Did They Have Opportunities to Grow in Their Understandings of Themselves and Their Relationships to Their Environment? Under the teacher's guidance, the children acquired some knowledge that could affect their behavior. They developed some understandings of why:

1. They should not put their fingers or such objects as pencils into their mouths.
2. They should wash their hands before they eat.
3. They should not drink water from canals and brooks.
4. They should cover their mouths with cleansing tissue when they cough and sneeze.
5. They should stay home when they have a cold.

Not only did the children have opportunity to develop good attitudes regarding personal health and sanitation, but also they gained in their understandings and appreciations of what the hospital, the local water department, the YMCA, the doctors, and the nurses do to safeguard the health of many people.

Did Their Experiences Provide Motivation for the Acquisition of Further Understandings? The way in which a series of new inquiries kept developing is evidence of their continued desire to seek further understandings, to increase the scope of the original inquiry, and to probe ever deeper into the area.

Is There Any Evidence that These Experiences Have Helped Them Acquire a Greater Social Consciousness? Did they gain any satisfaction from the knowledge that their mothers were right when they refused to allow them to swim in the canal? They learned of the unsanitary conditions that existed in the local brook and canal. They wished the city could make the canal water clean so they could swim there. They wanted to talk with the manager of the city water department so that they could find out what their city did to purify drinking water. There was some growth toward this fifth goal of science education. Further experiences similar to these will develop this beginning awareness of what group solidarity and action can accomplish. The confidence they gained increased the likelihood that each one of them will feel that he or she has an individual contribution to make.

These challenging experiences did not just happen to occur in this particular classroom. The climate or condition set up by the teacher and the administrative staff was conducive to their development. The teacher's careful planning, consciousness of the goals of science education, skill in helping these children answer their questions, readiness to adjust plans when the situation warranted it, and finesse in making each child feel that his contribution was important were also contributing factors.

Such conditions as those described are necessary for effective learning in any field of knowledge. Each teacher who feels a responsibility for helping children develop understandings, attitudes, and techniques necessary for effective problem solving can make experiences similar to these happen in the classroom. He, too, can learn and practice this method of inquiry.

How Many of the Process Skills Did the Children Practice? In almost any scientific inquiry, such skills as *observing, classifying, communication, inferring, and making operational definitions* are used. This particular inquiry started when the pupils *began to question the relative sizes of animals.*

The scope of the iniquiry was increased when one pupil asked, "How tall is a tree?" In the original activity the children *observed, classified, communicated, recognized number relationships,* and *drew tentative conclusions, or made an operational definition.* The depth and scope of the inquiry increased as each new inquiry was identified and solved.

When the pupils collected, prepared, and used the bottles, some of which contained air, others soil, and still others water, they were *experimenting* and *manipulating variables.* After the class observed the samples they *collected,* they *classified* the living things in the bottles into two groups—plants and animals. In this instance, they both *inferred* and *predicted* that the green things would be plants and the nongreen things that moved would be animals.

Although the *hypothesis* was only partially stated—"...If there were living things in the bottles, it might be possible to grow them. In what can we grow them?"—the class *formulated an hypothesis.*

In this series of inquiries, each member of the class had opportunities to practice 11 of the 14 process skills. Because the children were not referred to reading references, the inference can be made that there were none available. Therefore, the pupils could not *interpret data.* The inquiries did not lend themselves to the *formulation of models* or provide the opportunity to *recognize space-time relationships.*

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Chapter Three

The Science Program

Because science is a "newcomer" in some elementary school systems, classroom teachers are often puzzled about its role in the general education of children. These teachers have raised several questions that merit consideration: Should we teach science as an incidental program? Should we integrate it with other subjects as the occasion arises? Or should we teach science during a class period allocated for that purpose? Since all three types of program have merit, let's consider each of them separately.

How should the school provide the child's total science experience?

Incidental teaching

Many occasions arise in the classroom in which science can be taught best by utilizing the child's immediate interest in some unforeseen event or question that arises. Suppose one of the fish in the aquarium dies during the weekend. If incidental opportunities for teaching science are not used, the teacher may have to say, "I'm sorry. We can't investigate the reason for the fish's death until next month, or even next year, when we will learn about the conditions fish need to survive, or until we study the unit in fisheries in social studies."

What if an epidemic of measles breaks out in your school? What if a child brings an exciting, new toy to school? What if the children have just heard the news that a spacecraft has landed on Mars? Shall the teacher ask them to wait for an explanation until they are studying about these things in health, social studies, language arts, or until they arrive at a certain unit in the planned science program?

Teachers have learned that it is sometimes wise to interrupt and change plans at a minute's notice. They are fully aware that learning occurs most effectively when interest is high and when children are eager to discuss, to investigate, to read, and to find out by experiment. They know that what is taught on *these occasions* often results in better learning than more carefully laid plans. But *such incidental* teaching opportunities may never happen again. Besides, all these incidental learnings may cluster into one or two small areas of science. Children need broad experiences in all fields of science. It is improbable that an incidental program can provide the breadth and continuity of experience necessary to satisfy the needs of today's children.

Integration with other subjects

Because science is so closely related to the whole elementary school program, it is frequently difficult to distinguish from other kinds of school experiences. Teachers make notations similar to these in plan books: science and social studies, science and arithmetic, and science integrated with other subjects in the curriculum.

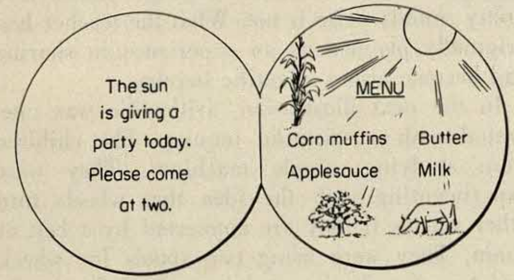
Children accept integrated experiences as natural occurrences in the learning process. Teachers also recognize them and utilize their professional skill to teach together those things that belong together.

The Christmas spirit vividly colors all the experiences of children before the holiday season. The following incident shows how one teacher integrated the children's experiences with the Christmas holiday. Members of the class brought their old toys to school to give away to less fortunate children. This was originally planned as an experience in sharing. When the children asked permission to use some of the toys for Christmas bells, the teacher, who had not anticipated that science would be involved, recognized a natural opportunity for integration and reorganized the children's activities to include experiences in science. The following year, he planned for this experience.

All the children were excited about the toys and wanted to sort them. It was decided to classify them by types. Dolls were put on one table, toy cars on another, and so on. There were many toys that made sounds. One child wanted to know if they might use these toys for Santa Claus bells in the Christmas play. Another said, "Christmas bells sound pretty. This one sounds awful!" It was suggested that all sounds may not be pretty. Thus, a question arose: Which toys make pretty sounds? Which toys do not? Much testing, much noise, and much listening followed. The result—two piles of toys that made sounds. The children said, "This pile of toys makes pretty music. This other pile is too noisy." They had formed a simple scientific concept: music is a pretty sound; noise is not. What the teacher had originally planned as an experience in sharing had become also a scientific inquiry.

In the next illustration, arithmetic was integrated with a scientific inquiry. The children were studying simple machines. They were experimenting with the idea that wheels turn other wheels if they are connected by a belt or chain. They were using two spools for wheels and two pencils, inserted into the holes in the spools, for axles. One spool was larger than the other. The children discovered that while the larger wheel turned once, the smaller wheel made two turns and a part of another turn. One child immediately suggested that the little bit more than one turn was half of the way around again. The teacher replied, "One day last week, we were learning what one-half means. We know how much one-half is." He helped them to use this previous experience in arithmetic to decide how far the smaller wheel would have to turn if it made one-half of a turn. The children drew a straight line across the end of the smaller spool. They saw that this line divided the end of the spool into two halves. Then the children saw that the smaller wheel did make two complete turns and a little bit more; but, this little bit more was not enough to be one-half. How much was it? Now the teacher suggested that they make another line to divide the halves into half again. The children could see that they had divided the end of the spool into four equal parts. When they again watched the big spool turn the smaller spool, they could see that the smaller one turned exactly two and one-fourth times during the time the big one turned once. In this experience, the children had developed learnings in both science and arithmetic.

It is often possible to integrate several subjects in the same activity. Arithmetic, art, language arts, nutrition, and science concepts were developed from this little party that was planned, prepared, and given by the children and their teacher as a culminating experience. Children love surprises. They love to give them and they love to be surprised. One morning the *principal* found a big, round, yellow piece of folded paper in his mail box. Inside the yellow paper the children had printed a short invitation and menu. After each item on the menu was a picture.



Beside the words *corn muffins* the children had drawn a picture of the sun shining on a green stalk of corn. Next to the words *apple sauce* was a picture of the sun shining on an apple tree. Following the words *butter* and *milk* was a picture of a cow eating grass and the sun shining on the grass.

During the preparation of the corn muffins and apple sauce, the children had measured the quantities of ingredients that went into them and the cooking time. They had figured how to cut the butter into the proper number of pieces and to estimate the amount of milk they needed for themselves, the teacher, and their guest.

Before the food was served, the children gave a short program. They explained that, without the energy from the sun, there would have been no cornmeal for muffins, and no apples for applesauce. They also explained that, without energy from the sun, there would have been no feed for the cow and without food energy the cow could not have produced milk and cream. "Without the sun's, energy we would have no food." This party experience provided a natural opportunity to integrate arithmetic, art, dramatics, letter writing, science, table manners, and table setting.

Numerous natural relationships, similar to the one described, exist between science and the other subjects taught in elementary school. When science experiences add meaning and fit naturally into the development of other school subjects, then science should be integrated.

A number of years ago, when "integration of subjects" became fashionable, integration was sometimes overdone. Today, teachers have learned that they can't integrate everything all the time. They realize that sometimes science can and should be integrated with other subjects and that sometimes the other subjects can and should be integrated with science. They have discovered the true meaning of the word *integration:* teaching together what naturally belongs together.

The specifically allocated science period

Schools are recognizing that it is important for all children to have a sequential development of science learnings and experiences and for children to explore widely and deeply all areas of science. To accomplish these two goals, they realize that the school program must allocate time for teaching science. A separate period for science provides time for greater scope and continuity in development than either the incidental or the integrated program can.

Scope in the elementary science program gives yearly balance as well as a total six-year balance in the fields of biological and physical science. If the planned program is well balanced in the biological sciences, it will contain science learnings from the areas of anatomy, physiology, health, safety, plant and animal communities, plant and animal adaptations, the reproduction of plants and animals, and man's use of, and effort to control, his biological environment. A well balanced program will also include physical science learnings in the areas of astronomy and space travel, chemistry, geology, heat, light, sound, magnetism and electricity, mechanics, meteorology, nuclear and other sources of energy, and man's efforts to use and to control his physical environment.

A planned science program provides experiences that increase the depth and scope of concept formation. Teachers who follow a planned science program are less likely to infringe upon the learnings and experiences planned for the higher grades or to repeat the experiences and experiments that children have had in lower grades. In schools that do not have a planned science program, such experiments as the crushing of the tin can and the hard-boiled egg and milk bottle, which are used to develop simple concepts about air pressure, sometimes have been repeated over and over again on different grade levels without expanding the concept or developing new ones. A planned science program avoids repetition and provides a sequence of experiences that broaden the concept.

Undue repetition, and the undesirable attitudes about science that form as a result, can be avoided by utilizing a planned program. Jim was causing trouble in his science class. When the principal heard Jim's side of the story, he realized that the child was simply expressing his boredom in a boylike fashion. Jim had studied the same "stuff" about the solar system four different times in the elementary grades, and now that he was in junior high school, he was suffering through it all over again. How much greater depth and scope in understanding Jim might have acquired if part of the time he spent in studying the solar system had been given to learning about space travel, about the heavenly bodies beyond the solar system, about the instruments used by astronomers, or about astronomy as the basis for navigation.

A well organized, independently planned science program eliminates wasted time of both learner and teacher and makes it possible to increase not only the scope but also the depth of the learning.

The combined method

If all children are to be given opportunities to explore the world of science as deeply and as widely as their learning capacities permit, the good qualities in each type of teaching must be included in a comprehensive plan for the school program; and the right hand must know what the left hand is doing. If children are to have opportunities within the limitations of the present school day and if science, as well as the other subjects in the elementary school, is to be enriched, administrators must devise a plan that will utilize effective teaching situations. The good points of all these methods of teaching must be combined, through careful, all-school planning, into a closely knit pattern of teaching, which both administrators and teaching personnel will support. Only a master plan can draw from the incidental type of teaching, its timeliness, sparkle, and challenge; from the integrated program, its time-saving element, its ability to relate many areas of knowledge to each other, and its practicability; and from the *independently planned* science program, its scope and sequence of experiences and learnings.

The teaching personnel and administrators need to sit together long hours and dig, and then dig some more, and then go into the classroom and experiment, before they can evolve a workable, effective total school program. They should draft the blueprint for this program only after giving careful consideration to children's interests, to the sequence of experiences and learnings that children need, and to all kinds of opportunities for the development of these interests and needs. The blueprint (see Table 3.1) should also provide the flexibility needed to permit the slow, the average, and the rapid learner and the gifted child to travel in his personal explorations to different depths and breadths. If John, in the first grade, wants to know about atoms, and Mary, in the fifth grade, wants to probe into the realm of the fourth dimension, a scheme must be devised to permit these rapid learners and gifted children to move further in these directions than the other children in the classroom. A planned science program is to be considered as a working base that can be altered to fit changing needs.

After a school has organized a basic science program from which to work, a simple means for checking group progress or the progress of individual children can be set up. Examples of such a chart and three ways to use it are shown in Tables 3.2, 3.3, and 3.4.

To fill out the Cumulative Science Record sheets, the teacher need only write the number of the grade under the inquiries studied by his group or individual children. The record sheets should accompany the children to the next grade, so that the next teacher can see at a glance the kinds of inquiries the children in the class have made.

How teachers and administrators can plan a local science program

Many school systems have found that a locally organized science program may be better adapted to their needs than the programs organized in textbook series or courses of study. They have also discovered that the in-service training that occurs during the planning and testing of a local science program helps to account for its success.

Table 3.1

AN EXAMPLE OF THE BLUEPRINT OR PATTERN OF PROGRAM BUILDING USED BY MOREAU SCHOOL FOR THE TOPIC—WEATHER CHANGES

Suggested Inquiries (See Chap. 8)	Basic Learnings (See Chap. 8 for Complete List)	Local Choice of Experiences	Local School Decision for Grade Placement
1. How can we find out whether air is real?	Air is real. Although we cannot see it, we can feel it and see the things it does.	(See Chap. 8.)	Kindergarten
2. Where can we find air?	Air is all around us. Air is found in water, soil, and in many things.	A card file of the suggested experiences which the school plans to use to explore the inquiries and develop the learnings may be organized and then mimeographed for distribution to all teachers. New experiences can be added to this file as they are developed in the classrooms.	Kindergarten
3. How can we find out whether air fills things?	Air fills things.		Kindergarten
4. What is wind?	Wind is moving air.		Kindergarten
5. What makes air move?	Heating air causes it to move. Cooling air causes it to move.		Second grade
6. How can we measure air temperature?	We measure air temperature with thermometers.		Second grade
7. How can we find out whether air has weight?	Air has weight.		Fourth grade
8. Which weighs more: warm air or cool air?	Cool air weighs more than warm air.		Fourth grade
9. What happens if some air is cool and some air is hot?	Warm air rises and is replaced by cool air. Cool air mixes with warm air.		Fourth grade
10. How can we learn whether there is water in the air?	Even though we cannot see it, there is water in the air.		Fourth grade
11. How does water get into the air?	Water evaporates into the air.		Fourth grade
12. How does the weatherman measure precipitation?	A rain gauge is used to measure precipitation.		Fourth grade
13. How can we find out whether air has pressure?	Air presses in all directions.		Fourth grade
14. How does the weatherman measure air pressure?	A barometer is used to measure atmospheric pressure.		Fourth grade
15. How does the weatherman measure wind direction and speed?	Weather vanes and wind socks are used to determine wind direction. Anemometers are used to measure wind speed.		Fourth grade
16. How does the weatherman measure the amount of water vapor in the air?	Weathermen use psychrometers to measure the amount of water vapor in the air.		Fourth grade

17. What are the characteristics of *high-* and *low-pressure* areas?	A high-pressure area is a region where the air mass is cooler and dryer than it is in a low pressure area.	Sixth grade
What causes high- and low-pressure areas?	Unequal heating of air is one cause for high- and low-pressure areas.	
18. What are warm and cold fronts? How are they formed?	A cold front is a boundary where a moving mass of cool air meets a mass of warmer air. A warm front is the boundary where a moving mass of warm air meets a mass of cooler air.	Sixth grade
19. What are some of the records the Weather Bureau uses to make its forecast?	The Weather Bureau uses past records, trends, regional weather conditions, and weather station reports.	Sixth grade
20. What are some of the recent discoveries and inventions that may make it possible to control weather?	Man is learning how to use chemicals, electronic devices, nuclear energy, and ultraviolet light to control weather patterns.	Sixth grade

Table 3.2

CUMULATIVE SCIENCE RECORD

School (Child) Moreau School *

Dates: Starting 19- Finishing 19-

Purpose Class Record

Inquiry Numbers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29‡
Topics† Weather	k	1	1	k	1	2	3	3	3	4	4	5	4	5	5	5	5	5	5	5									
Magnetism																													
Electricity																													
Plants and Animals																													
Solar System																													
Beyond the Solar System																													

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* Notice how Moreau School has changed the *weather sequence* and its *grade placement*. If this change continues in this sequence and in others, it is a good indication that their program has been adjusted to local needs.

† Use a row for each topic in the planned program.

‡ To largest number in any topic.

Table 3.3

CUMULATIVE SCIENCE RECORD

School (Child) John Hall *

Dates: Starting 19- Finishing 19-

Purpose Above Average

Inquiry Numbers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29‡
Topics† Weather	k	1	1	k	1	2	3	3	3	4	4	4	4	4	4	4	4	4	4	4									
Magnetism																													
Electricity																													
Plants and Animals																													
Solar System																													
Beyond the Solar System																													

* Working by himself, John finished the weather sequence in the fourth grade.
† Use a row for each topic in the planned program.
‡ To largest number in any topic.

Table 3.4

CUMULATIVE SCIENCE RECORD

School (Child) Harry Jones *

Dates: Starting 19- Finishing 19-

Purpose Slow Learner

Inquiry Numbers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29‡
Topics† Weather			4		4	4	4	4	4	5	4	5	5	5	5	6	6	6	6	6									
Magnetism																													
Electricity																													
Plants and Animals																													
Solar System																													
Beyond the Solar System																													

* In the fourth grade, Harry worked on simple problems he had missed and completed the sequence in the sixth grade.
† Use a row for each topic in the planned program.
‡ To largest number in any topic.

A typical procedure followed by many school systems starts with an orientation workshop led by curriculum and science specialists. At this orientation workshop, the members, together with the specialists, outline the kind of science program which they would like and discuss how they can work as a team on such a curriculum study.

Their work plan usually includes an in-service workshop for those teachers who wish to increase their own knowledge of science and who believe that they need more practice in the process skills of critical inquiry. Another may study available textbooks to determine the grade placement of science areas and learnings. Still another group may survey available courses of study for the same information. Finally, committees of teachers representing each grade level use the reports from these studies to select and plan for each grade a sequence of learnings with the experiences for developing them. The whole school system (children, teachers, and administrators) becomes a testing laboratory for this proposed science program. This kind of local planning and curriculum development is a continuous process in some schools because they are constantly revising their program in order to update it, readjust grade placement, and increase its depth and scope.

How a classroom teacher can plan a science program for one grade

A teacher may be assigned a school that has no comprehensive school science program. If this is so, he will need to plan a balanced science program for the grade taught.

Study good science textbook series as well as state and city courses of study. These will be helpful for selecting a variety of areas from the biological, physical, and earth science fields for a balanced plan. If these textbooks and courses of study are well planned, they contain both a small sequential development of science learnings for one grade and a sequence which extends from one grade to the next.

If some kind of science record accompanies the children from grade to grade, it should, as a minimum, list the science areas in which the children have had experiences. These records can help a teacher outline the next year's science program. If there is no record of the children's previous work in science, try to learn what it was by talking with their former teachers. With this information draft a science program for the year and submit it to the administrator for approval.

Part Two of this book presents a sequential development of many areas from the fields of biological, physical, and earth science. This part of the book can be used to select a variety of areas from each field to plan a balanced yearly program. In each area, the presentation starts with the very simplest inquiries, experiences, and learnings and advances step by step to more complex ones. If children are working in an area for the first time, begin with the first inquiries and go as far as seems appropriate. Do not underestimate the children's capacity to explore science inquiries. Their "sciencing" and the depth to which they will go in a given area will be surprising. Some of the more difficult inquiries may be just the kind of challenge needed by fast learners and gifted children. *Stop* whenever the next inquiry is too advanced. In a sequential plan, the more difficult inquiries may be explored by *fast learners and gifted children* or by children *at a higher grade level.*

ADDITIONAL READING

Association For Childhood Education International, *Science for the Eights-to-Twelves,* Washington, D.C., 1964–65. Membership Service Bulletin No. 13-A.

Association For Childhood Education International, *Young Children and Science,* Washington, D.C., 1964–65. Membership Service Bulletin No. 12-A.

Gruver, William J. and Albert Pitz, *Modern Science and Your Child,* U.S. Dept. of Health, Education, and Welfare, Office of Education. Washington, D.C.: Government Printing Office, 1963.

National Science Teachers Association, *It's Time For Better Elementary School Science.* Washington, D.C., 1958.

Nelson, Henry B., ed., "Rethinking Science Education," *The Fifty-ninth Yearbook of the National Society for the Study of Education.* Chicago: The Society, 1960.

Tannenbaum, Harold E. and Nathan Stillman in collaboration with Albert Piltz, *Evaluation in the Elementary School,* U.S. Dept. of Health, Education, and Welfare, Office of Education. Washington, D.C.: Government Printing Office, 1964.

Chapter Four

Evaluation

Most educators agree that science teaching should be directed so that each pupil has opportunities to:

- **Acquire science learnings, understandings, and concepts;**
- **Practice the process skills of critical inquiry and the methods of inquiry;**
- **Develop desirable attitudes which can influence present and future behavior.**

If teachers and administrators accept these three goals, then they must not only (1) direct their science teaching toward each, but also (2) *direct their evaluation techniques toward measuring the progress of pupils in each.*[1]

Techniques for evaluating children's progress in the acquisition of science learnings, understandings, and concepts

In the evaluation of progress toward the acquisition of *science learnings, understandings,* and *concepts,* teachers commonly use various forms of objective tests. Objective tests provide opportunities for pupils to make their responses by either supplying or selecting a short answer. These tests are good for measuring knowledge of specific facts. They also allow the teacher to measure a large body of subject matter. The following kinds of objective test items are useful techniques for the evaluation of this goal.

True-false test item

True-false test items are simple declarative sentences. However, they *are difficult to construct,* because each item must be either completely true or completely false. A variation of the true-false item can be used to reduce guessing. In the variation, the pupil is asked to correct the statement, if it is false. EXAMPLE: The nearest star is Alpha Centauri (*false; the sun*).

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[1] Harold E. Tannenbaum and Nathan Stillman in collaboration with Albert Piltz, *Evaluation in Elementary School Science, U.S. Dept. of Health, Education, and Welfare, U.S. Office of Education.* Washington, D.C.: Government Printing Office, 1964, pp. 34–38.

Supply test item

The supply test item reduces the possibility of guessing. EXAMPLE: What instrument is used to measure temperature? (*thermometer*).

Matching test item

Matching test items are usually arranged in two columns which bear a definite relationship to each other. They can be used to measure a pupil's ability to associate events with persons or places, to associate terms with their definitions, principles with examples, and chemical symbols with the names of chemicals. EXAMPLE:

COLUMN I	COLUMN II
C 1. anemometer	A. measures atmospheric pressure
A 2. barometer	B. measures temperature
D 3. hygrometer	C. measures wind velocity
B 4. thermometer	D. measures humidity

Multiple-choice test item

In a multiple-choice item the pupil is given several choices from which to select the one which best answers the question or best completes the sentence. Usually four or five choices are given. The multiple-choice item is considered the most valuable and flexible of all because it can be used to measure a pupil's ability to understand and to reason as well as his ability to recall factual knowledge. EXAMPLES: If a large room and a small room are both heated to the same temperature, we may say that:

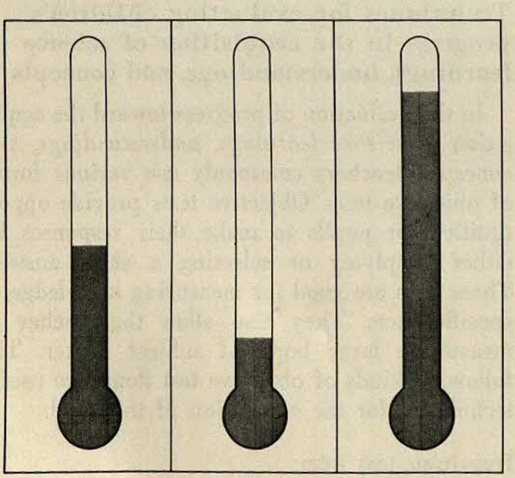
a. the small room has more heat
[✓ b.] the large room has more heat
c. the small room will cool faster
d. the large room will cool faster
e. they both have the same amount of heat

What does a drop in barometric pressure indicate?

a. fair weather
[✓ b.] stormy weather
c. warmer weather
d. cooler weather
e. fair and colder weather

In the primary grades when the pupils lack reading skills, multiple-choice tests can be given orally with the teacher reading the directions. For Fig. 4.1, he says, "Make a large *X* on the thermometer which shows a hot day and a small *x* on the one for a cold day." For Fig. 4.2, "Make a large *X* on the picture which has no rain clouds and a small *x* on the one which has clouds from which rain will fall. These figures test the children's science learnings. Observe that these pictorial items also measure the ability of kindergarten and first grade children to observe, compare, infer, predict, and apply several of the learnings they have made in their study of weather. These learnings are being tested.

Fig. 4.1 A pictorial multiple-choice test item for children who lack reading skills.



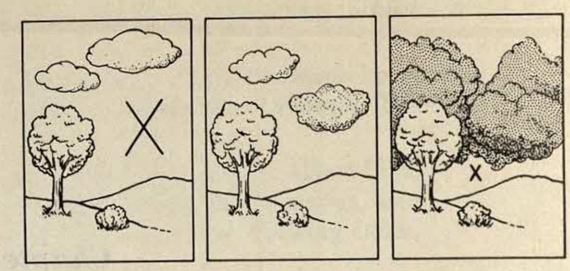


Fig. 4.2 Another pictorial multiple-choice test item.

1. The red (blue or silver) liquid in a thermometer moves up in the tube on a hot day and down on a cold day.
2. Rain comes from clouds in the sky.
3. Dark clouds are rain clouds and white clouds are fair weather clouds. It is likely to rain when there are dark clouds in the sky.

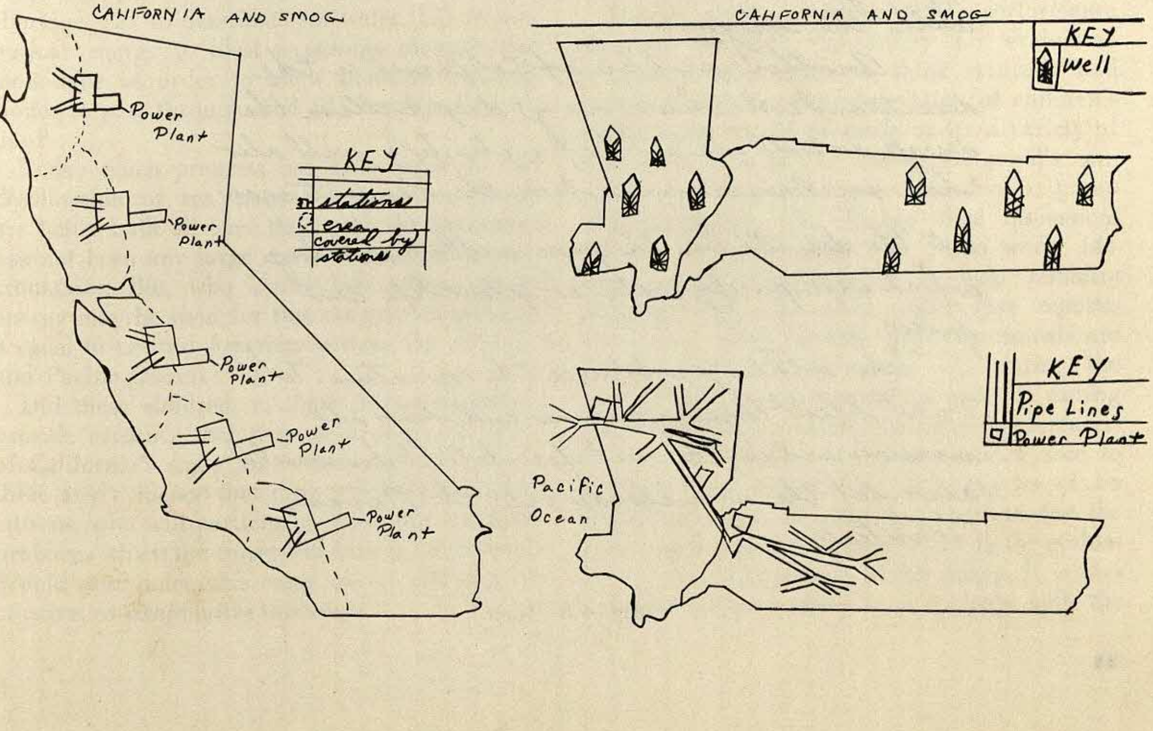
Techniques for evaluating children's progress in the practice of the process skills of critical inquiry[2]

Essay test item

Essay tests are appropriate when a teacher wishes to determine how well pupils can explain, compare, make inferences, draw conclusions, and select significant data to apply in a new situation. The chief merit of an essay test is that it provides the teacher with an opportunity to determine *the degree* to which a pupil can analyze the inquiry select relevant information, present evidence, organize answers logically and effectively, and *to think imaginatively*. This is because in an essay test (unlike in most objective tests) it is possible for the answers to be *partially right* and *partialy wrong*. Because of this characteristic the teacher can determine the *degree of correctness*.

The following is an essay evaluation technique used by a sixth-grade teacher. His class had worked with the following inquiries: (1) What causes changes in the weather? (2) What tools are used by meteorologists to measure, record, and predict weather changes? (3) What inquiries are meteorologists making that may lead to the control of weather conditions? In order to provide for individual differences, *two assignments* were given and the pupils were permitted to work alone or in committee. The assignments were as follows: (1) Choose some part of the world and make a written proposal that you think would improve the region. (2) If you feel that you need to *further investigate* any part of the inquiries we already have made, you may do so. State your inquiry and do the studying and experimenting you consider necessary in order to write a composition that describes the results of your work. Permission was given in this assignment for the pupils to use any references and equipment they wished and to make or use any visual aids that would clarify their

Fig. 4.3 A sixth-grade committee report on California and smog.



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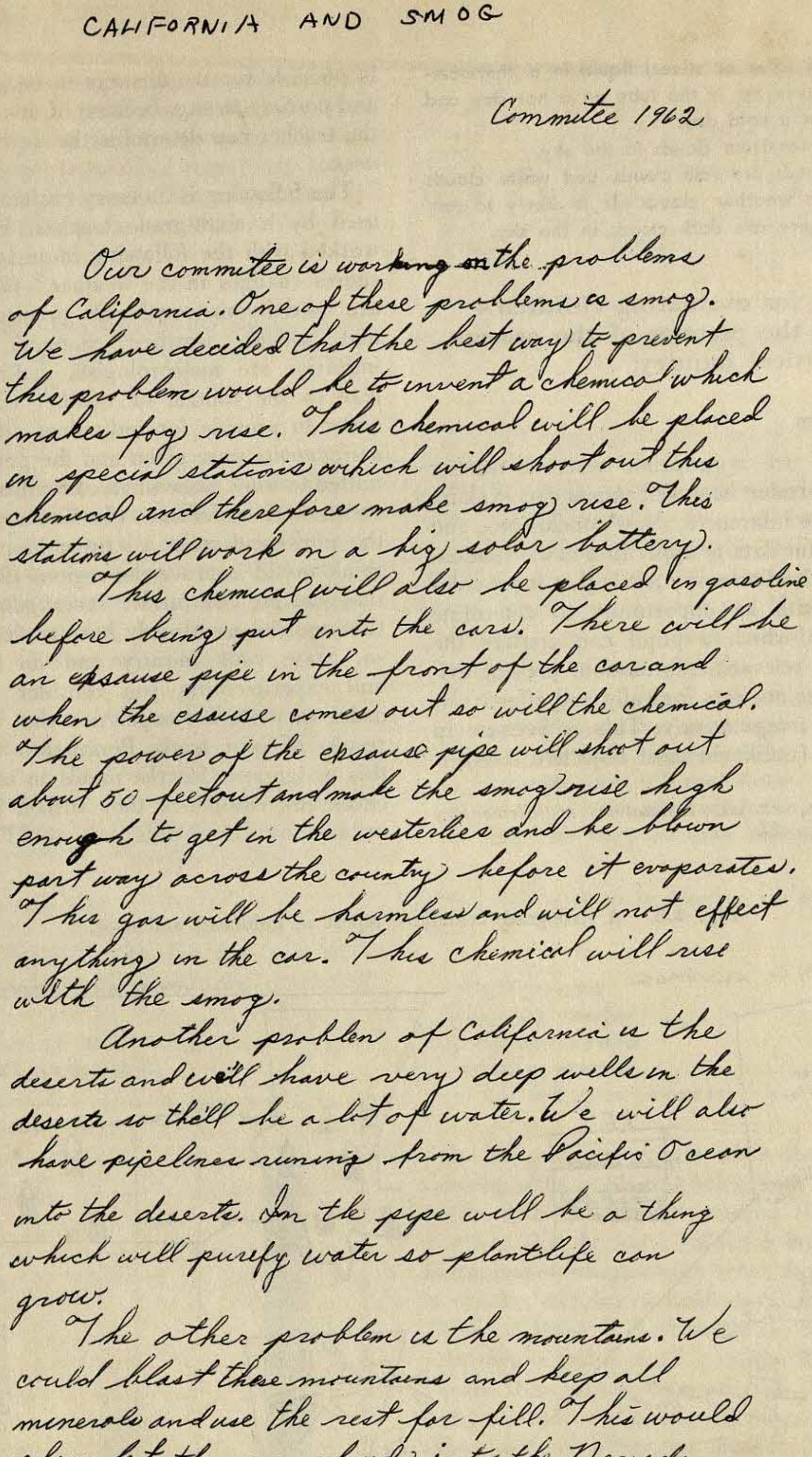
[2] Tannenbaum, *et al., Evaluation in Elementary School Science*, p. 27.



CALIFORNIA AND SMOG

Commitee 1962

Our commitee is working on the problems of California. One of these problems is smog. We have decided that the best way to prevent this problem would be to invent a chemical which makes fog rise. This chemical will be placed in special stations which will shoot out this chemical and therefore make smog rise. This stations will work on a big solor battery.

This chemical will also be placed in gasoline before being put into the cars. There will be an epsause pipe in the front of the car and when the esause comes out so will the chemical. The power of the epsause pipe will shot out about 50 feetout and make the smog rise high enough to get in the westerlies and be blown part way across the country before it evaporates. This gas will be harmless and will not effect anything in the car. This chemical will rise with the smog.

Another problen of California is the deserts and will have very deep wells in the deserts so thell be a lot of water. We will also have pipelines runing from the Pacific Ocean into the deserts. In the pipe will be a thing which will purefy water so plantlife can grow.

The other problem is the mountains. We could blast these mountains and keep all minerals and use the rest for fill. This would also let the rain clouds into the Nevada Territory.

Fig. 4.3 (*cont.*)

work. When the assignment was completed, each child or committee presented an essay, visual aids, demonstrations, and conclusions. Figures 4.3 and 4.4 show two of these essay reports as the pupils originally drafted them. Both of these essays were written in the school year 1961–62. How would you evaluate the abilities of these pupils: (1) to identify and define the inquiry, (2) to apply concepts to a new situation, (3) to formulate hypotheses, and (4) to draw tentative conclusions? These essays have not been edited. Spelling, sentence structure, and punctuation are uncorrected. Because these compositions were written in a science class, they should be evaluated first for the goals of science, not for the goals of language arts. Grammatical errors and misspellings should be corrected, but they should not be taken into consideration when a science evaluation is made.

The committee who prepared the essay on California made four recommendations. Remember that this essay and its proposals for smog control were written in the early 1960's.

It was not until the late 1960's that California passed a law stating that *something* must be done to eliminate the impurities in automobile exhaust gases which are known to be a major factor in the production of smog. This law was passed before any practical solution to the problem was available. What do you think of the children's proposals (1) to eliminate California's water shortage, (2) to desalinate sea water, (3) to use nuclear energy to blast a passage through the mountains in order to allow moisture bearing clouds to pass through, and (4) for fog elimination?

Today much progress has been made in the desalination of sea water. Desalination plants are being built all over the world. As yet, there has not been any large scale nuclear blasting of mountains. But, who knows how soon nuclear energy may be used for this purpose or to blast a canal in Central America between the Atlantic and Pacific Oceans?

Did these children, in their illustrated essay, provide evidence that they were aware of some of California's smog and weather problems? Is there any evidence that they will become active citizens, who will participate in solving scientific problems which the world will face in the future? Would you judge this essay as an evidence of creative, or imaginative thinking?

The essay on the *Barometer* provides evidence that the children in this committee could identify their personal problem and were willing to try to solve it. These is also evidence that these children could draw diagrams to show correctly the causes for high and low pressure barometric readings and could use graphs to keep accumulated data. But, their concept was not clear enough for them to correctly record it in written form. The graph made by the children is interesting also. These sixth-graders probably were unable to adjust the barometer correctly. (See Fig. 4.4.) If the barometer really was adjusted correctly, their bar graph readings indicate that they were in the midst of an extremely low pressure area—so low in fact that on several days their community was in the midst of either a tornado or a hurricane. How would you evaluate the illustrated essay written by these children? How much is right; how much is wrong? Would you give this report a failing grade? If so, review the inquiries the class made and the teacher's assignment. How would you help the students *discover* the fallacies in the essay? What experiences would you suggest to help the students correct their errors?

Observation-performance tests

Observation-performance tests can be used to detect growth *in the use of the process skills of critical inquiry*. See page 16.

Teacher observation of a pupil's performance also can be used successfully for evaluating progress in the ability to think critically and imaginatively. Teacher observation of children's performance should be made under a variety of situations, such as (1) during the pupil's construction of models for either personal or group experimentation, (2) during class discussion, (3) during independent and group work, (4) when pupils make models to help *visualize abstract ideas*, (5) when pupils give reports, (6) during work periods when experiments are being assembled and tested, (7) during the planning of classroom activities, and (8) during teacher-pupil and teacher-committee conferences.

Observation-performance tests can be used to evaluate class progress or the progress of an individual child. It often is important for the class to participate with the teacher in the evaluation of the achievements of the group. It is also valuable for each child to participate with the

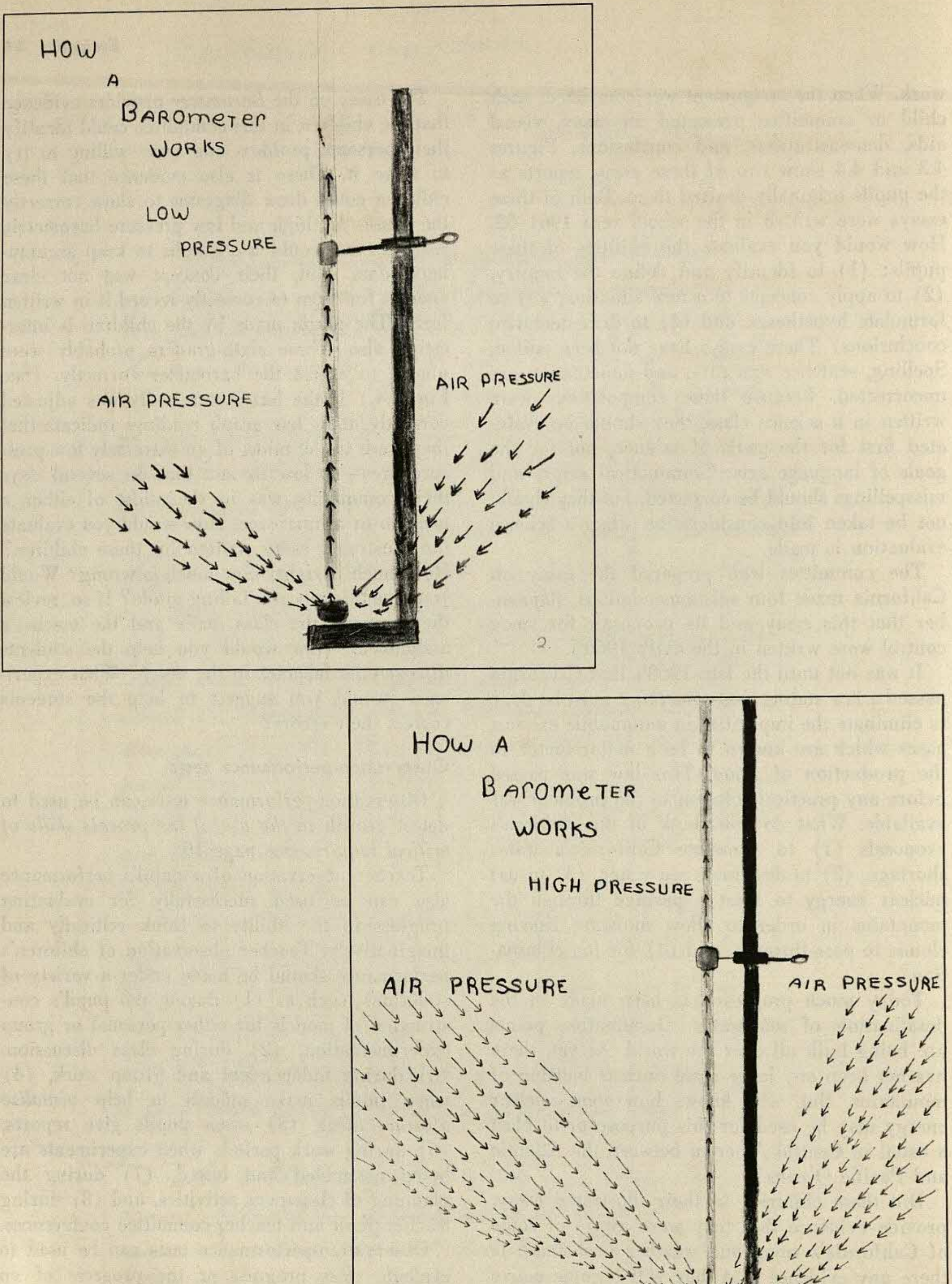
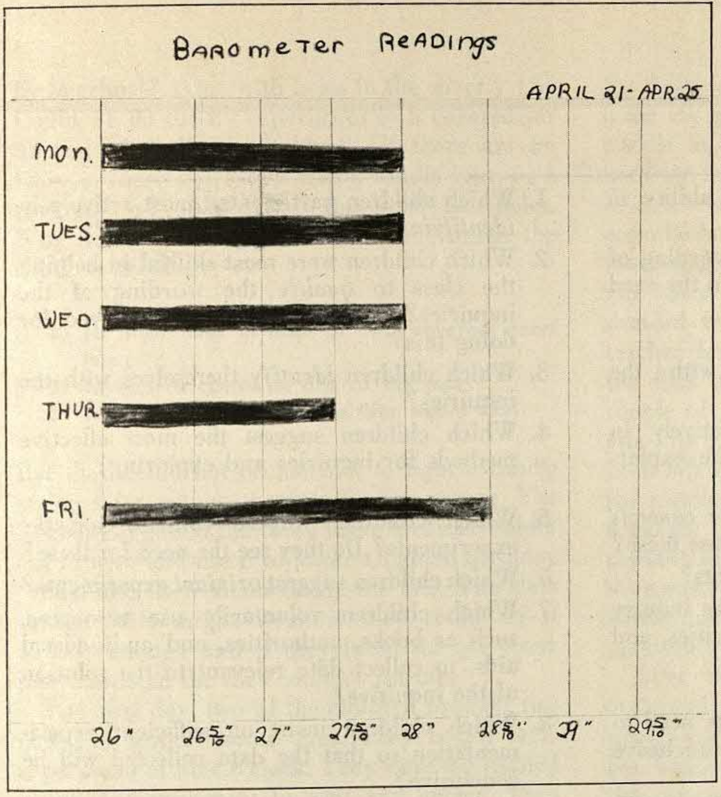


Fig. 4.4 A sixth-grade committee report on how the barometer works.



Barometer

① Our committee has been working on the barometer We made one so we could understand it better this is a diagram of it ②. This picture shows how a barometer works Air-pressure comes down on this cup the murkury goes farther up the glass tube. ③ If there is less air pressure on the cup the murcury rises higer into the tube you have high pressure ④ We measured our barometer every day at about 3 00 P.M These are the readings we have.

Fig. 4.4 *(cont.)*

Table 4.1

THE TEACHER EVALUATES

Group	Child
1. Do they show progress in their ability to *identify and state* the inquiries?	1. Which children participated most actively in *identifying and stating* the inquiries?
2. Are they learning to *qualify* the wording of their inquiries? Do they understand the need for doing this?	2. Which children were most skillful in helping the class to *qualify* the wording of the inquiries? Which children see the need for doing this?
3. Do they *identify* themselves with the inquiries?	3. Which children *identify* themselves with the inquiries?
4. Does the group participate effectively in planning methods for inquiries the exploring?	4. Which children suggest the most effective methods for inquiries and exploring?
5. Do they see the need for adequate *controls* for the experiments? Do they propose these?	5. Which children propose *controls* for the experiments? Do they see the need for these?
6. Do they suggest *original* experiments?	6. Which children suggest *original* experiments?
7. Can they collect data relevant to the inquiry from such sources as books, authorities, and audio-visual aids?	7. Which children voluntarily use resources, such as books, authorities, and audio-visual aids, to collect data relevant to the solution of the inquiries?
8. Do they recognize that experiments need to be done more than once to collect conclusive data?	8. Which children insist on sufficient experimentation so that the data collected will be conclusive?
9. Do they question the validity of the results of their experiments?	9. Which children question the validity of the results of the class experimentation?
10. Do they check their results with authorities?	10. Which children find sources of authoritative evidence to corroborate the class results?
11. Are they satisfied with the results they get from their methods of inquiry?	11. Which children realize the point at which the inquiry is answered?
12. Are they using the new vocabulary developed in this inquiry?	12. Which children use the new vocabulary developed in this inquiry?
13. Can I honestly rate my children higher this time on their abilities to explore inquiries than I rated them on an earlier evaluation?	13. Can I rate more children in my class higher in their ability to explore inquiries than I did on an earlier evaluation?
14. Are they showing a desire to increase the scope of their inquiries?	14. Which children continue independently to explore further related inquiries?

teacher in evaluating individual progress. See Table 4.1.

A primary class wanted to try an experiment about which they had read. The book said that a candle needs air to burn. The pictures in the book showed two candles. One was burning and one was not. The one that was not burning was covered by a water tumbler. The class did the experiment several times, and each time they placed the tumbler over the lighted candle, the flame went out. But one child who was very interested in science wasn't satisfied with the results. He said, "Is the air all gone? Could a fly live in that tumbler?"

Although the teacher did not know the answer, he believed *in encouraging children to question* and *to investigate*. He helped the class plan an experiment for the next day. During the discussion of how they were going to set up the experiment, one child suggested that it might be difficult to get a fly under the tumbler after the candle went out without letting more air into the tumbler. This posed a real question. For a while the teacher let the children probe; however, because part of this question was too difficult for these young children, the teacher aided their planning by asking such leading questions as: (1) In what kind of container will you bring the fly to school? (One with holes in the cover.) (2) Could we do the fly experiment in a covered jar instead of under a tumbler? (If there are no holes in the cover.) (3) Will a candle burn in a covered jar? (Not unless the cover has holes. Why don't we try it?) These are the things the children decided:

1. To place flies in each of two covered quart jars;
2. To burn a candle in one of the jars;
3. To find out how long the flies would live.

But they could not decide how to light a candle inside a jar without having the flies escape. The teacher suggested that they make a candle-holder out of wire and use it to lower a lighted birthday candle into the jar containing the flies. The class thought this might work if they could do it quickly enough and if they lifted the jar cover just a little so the flies couldn't get out.

The next day, two of the children brought two jars and several house flies. They began their experiment at nine o'clock. They were too excited about the experiment to wait any longer. They put the same number of flies in each of the two jars, and they fitted a candle into a wire candle-holder. At last they were ready for the experiment. One child unscrewed the lid and got ready to lift the cover. A second child was all set to light the candle. A third child stood ready with a ruler to steer the candle in its wire holder into the jar and to help fasten the upper end of the wire candle-holder over the edge of the jar. When the lighted candle was inside the jar, the cover was tightened. The candle went out! The flies acted stunned for a few minutes. Then they slowly crawled up to the top of the jar. As the children shook the jar around, the flies acted a little livelier. They lived until lunch time. The flies in the jar in which no candle had been burned were still alive. The next morning they too were dead.

The children wondered why the flies lived until noon in the jar in which the lighted candle was extinguished. Through previous experiences, they had learned that fire needs air to burn. They also knew that such animals as flies use air to carry on their life processes. The teacher, who was aware of their inferences, asked the students to make *educated guesses* as to the reasons why the flies continued to live in the jar with the lighted candle. They made some of the following guesses (predictions): (1) Maybe some air got into the bottle when we placed the candle in it; (2) Maybe all of the air wasn't used by the candle; (3) Maybe flies don't need as much air as candles do. The class decided to see whether they could find some books to help them with their new inquiry, but neither they nor their teacher could find any. Next, they decided to ask the junior high school science teacher for help. He was a little surprised that the flies had lived. But he said, "I'll make a couple of *guesses* and *check them with books*." His first guess was that some *oxygen* must have been left in the jar, because the flies lived after the candle went out. His second guess was that a candle cannot continue to burn in this *small amount* of oxygen. He found that his guesses were correct. In this inquiry, a person who knew where and how to look for the information the children needed proved to be most helpful.

After this experience, the classroom teacher evaluated the problem-solving abilities of the group and of the individuals in it with a checklist, which was similar to Table 4.1. In evaluating this successful experience, the teacher appraised the skill of the class and of the individuals in it. If he had recorded his evaluation, it would have looked something like Table 4.2.

This classroom experience illustrates how oversimplification of science content can lead to the formation of misleading concepts. The candle did not go out because it had used up the air in the jar. It did not go out because it needed air to burn. It needed the oxygen which is in the air. The candle went out when there was not enough oxygen in the air to support burning. Children who are old enough to develop understandings about some of the conditions essential for burning are old enough to use the correct vocabulary to express these understandings.

The preceding checklist of evaluative questions for the *group* and the *individual* and similar ones that follow in this chapter are only suggestive. The use of these or other checklists can help the group or the individual child to realize what skills, abilities, and attitudes the teacher thinks important and thus to know what he is using as an evaluation or a measure of their growth. Perhaps evaluative questions such as these can best be used with a *group* in an open discussion period. *Individual* evaluation should be done informally and privately. The number of such questions used at any one time must depend on

Table 4.2

EVALUATING THE EXPERIENCE WITH FLIES

Inquiries: Does a candle flame before it goes out use all the air in a closed container?
Before it goes out does it use *all* the oxygen in the air?
Can flies live in a closed container after a candle has been burned in the container?
Can flies live on less oxygen in the air than is needed to keep a flame going?

Class	Individuals
This inquiry developed so fast, I felt that if I were to insist on its definition, qualification, and clarification, I would stifle the intense drive the children exhibited for its solution.	*Dick* initiated the experience with the flies. *Mary* raised the question of how to get flies into a jar.
100% of the children identified themselves with this activity.	
There was wide participation in the planning. The planning was effective. They all agreed that we should have flies in a control jar in which no candle would be burned.	*Alvin* insisted the two jars must be the same size. *Susan* said the covers must not have holes in them when we did the experiment. *Harry S.* proposed the two-jar technique, where one jar was a control for the experiment. This was *Dick's* original question, but *Lucy, Thomas, Peter,* and *June* helped greatly with original proposals for getting it answered.
They tried with little success. I had to help them with the composition of air, by reading to them a section from a fifth-grade book about the different gases in the air.	
They have some extra flies we didn't use today and they want to use them in a second experiment. I have said they may repeat the experiment tomorrow.	*Clayton, Phillip,* and *Marion* insist that we should try this again to be sure about the results.
They checked with the junior high teacher.	*Dick's* original comment about the candle using "an awful lot of air in an awful short time" indicated he questioned the results. *Clayton, Phillip,* and *Marion* are questioning the results of the fly experiment because they are not sure that it will happen again tomorrow.
Oxygen was a new word.	Quotes: *Abraham:* May I open a window? I think we need some oxygen in here. *Peter:* We have tropical fish at my house. We use a pump to put air into the aquarium because our fish need oxygen. *Paul:* Last night the man on the TV news said the tank trucks were putting oxygen in the rocket. Do rockets use oxygen? Do they breathe oxygen or does their fire use oxygen?
Most children are satisfied, but I suppose I'll need to satisfy all of them by suffocating a few more flies.	
This has been a high point in the children's ability to discover. They tore through this inquiry like a tornado through a town.	Each child participated more fully than he ever did before.
	Paul wanted to find out about the liquid oxygen used in rockets.

the teacher's judgment and on the maturity of the children. Not too many questions should be used at one time. Occasionally older children may be given a selected list of evaluative questions and asked to write their opinions. Sometimes the children should write an evaluation of the *group* effort; at other times, an evaluation of their *personal* contributions. The teacher can summarize the best points made by the group in these written opinions and state his observations concerning class growth in these skills, abilities, and attitudes. In private conferences with individual children, he can point out their personal strengths and weaknesses.

Children can be guided to evaluate their own abilities to state inquiries. One first-grade teacher helped his class to realize that the *words* they use and the *exact way* in which they express their questions are important. The project described next helped the students get practice in *defining* an inquiry and in *selecting the vocabulary* that would state exactly what they wanted to know.

This class had become interested in a memo pad that held a metal pencil. They asked many questions about it and decided as a group that they wanted to know (1) *What makes the pencil stick to the pad?* (2) *Will everything stick to the pad?* The teacher wrote these two questions on the chalkboard where they could be left until they were answered.

Only after the teacher had helped the children to discover that iron or steel objects placed near the memo pad were attracted to it because the pad was a magnet, and only after he had helped them to develop a vocabulary which included the words *magnet, attract, iron,* and *steel,* did he help them to reword their inquiry. He read their two original questions and asked whether they thought they could use better words and whether they wanted to change the questions in any way. One child said, "*Attract* is better than *stick.*" When they put the word *attract* in the sentence, it read, "*What makes the pencil attract the pad?*" The children said this was wrong because the magnet in the pad attracts the pencil. The next suggestion was to exchange the words *pad* and *pencil* so that the question would read: "*What makes the pad attract the pencil?*"

When the teacher asked whether they thought the question was now worded correctly, most of them agreed. One child said, "We found out that the magnet in the pad causes the pad to attract the pencil. Couldn't we use the word *cause?*" They decided that it would be even better to ask, "*What causes the pad to attract the pencil?*"

The teacher read the second part of the original inquiry: *Will everything stick to it?* Immediately the children decided to use the word *attract* instead of the word *stick.* The teacher asked them whether they thought they had tested *everything:* "Can you think of anything which you did not try?" Some of the untried things which they quickly named were the sun, the moon, the stars, and fish. One child even named uranium. After trying a number of ways to express the question, the children finally agreed that what they should have asked was: *What are some of the things the memo pad will attract?*

The children agreed that they should always try to use the best words in such a way that the question would ask exactly what they wanted to know. The teacher was also satisfied that their reworded inquiry would prevent the children from forming a misleading concept. He knew that the school did not have all the known things which magnets attract and that in their exploration of the inquiry, the children would be able to discover only two of them (iron and steel). He also knew that unless the question was qualified (What are *some* of the things...), the children would develop a misleading concept.

At the time an inquiry is raised, the children should be encouraged to state it in the form of a question and to define and qualify it as clearly as possible. Sometimes young children do not have the vocabulary necessary to define and qualify a question accurately. If this is true, the question as originally stated by the children should be restated by them, after they have had sufficient experiences and developed the necessary vocabulary. Older children who have a larger vocabulary and who have had previous practice in clarifying their questions should be encouraged to use these skills to define and qualify each new inquiry properly at the time it is first raised.

Children who, with their teacher's help, actually go through this defining, qualifying, and clarifying process are *identifying* these inquiries as their own. If the inquiry is theirs and not one the teacher has given them to explore, they are likely to have stronger motivation to find an answer.

Children can be guided to evaluate how effec-

Table 4.3

TEACHER AND CHILDREN EVALUATE

Group	Child
1. How well did we answer our inquiry?	1. How well do you think you answered this inquiry?
2. What might we have done better?	2. What part of the plan do you think was good? Bad?
3. How could we have improved the methods we used?	3. What would you have done to make our plan a better one?
4. Can we think of some better methods of attack which we did not explore?	4. Do you think we rushed into the chosen method of attack without deciding whether it was the best one?
5. Should we have used several different methods of attack at the same time?	5. Do you think this inquiry was the kind that is explored best by using several methods of attack at the same time?
6. What scientific controls, if any, should we have remembered to use for this experience?	6. What scientific controls, if any, did you suggest for use in this experience?
7. How much of our plan did we make ourselves and how much did we borrow?	7. What part of this plan did you help us with? Did you find the plan any place?
8. What science learnings, which we already knew, did we use to help us explore this inquiry? Did we have other knowledge that we could have used but didn't?	8. What science learnings did you use that you already knew? Did you fail to use some learnings that would have helped you?
9. What authorities did we go to for help with this inquiry?	9. What authorities did you use to help explore this inquiry?
10. Did we do this experiment enough times so that we are sure that our results are right?	10. Did you have a chance to do this experiment yourself? Were your results the same as those of the other children? Was this experiment tried enough times so that you are sure the results are right?
11. Are we satisfied that our answer is the right answer?	11. What results did you get? Do you think they are right?
12. With what authorities have we checked to see whether they agree with our results?	12. What authorities did you find who gave the same answer you did?
13. Are we using the new vocabulary developed in this experience?	13. What new words did you learn? Do you use them?
14. In what ways have we done a better job than we usually do?	14. Do you think you explored this inquiry better than you have explored others?
15. In what ways have we learned to be more scientific?	15. What did you do to help solve this inquiry that you think a scientist would have done?

tively they explored their inquiries by a teacher who asks them questions such as those in Table 4.3. By modifying the questions, he can use them to help the children evaluate their group or help a child to evaluate his own effort.

Dick, a third-grader, brought a Monarch caterpillar to school. No one in the class knew what kind of caterpillar it was. The children were fascinated by the beautiful colors of this young insect and were anxious to make a good home for it so they could watch its development.

When these children were in the second grade, they had brought to school some soil from a meadow. They had also been careful to bring the plants that were in this soil. They placed these materials in a large glass container. They kept the plants watered, picked off the dead leaves so that mold would not grow, and made certain that the plants had sunlight. One morning, more than a dozen baby grasshoppers crawled out of the soil where they had hatched from their eggs. As the days passed, the grasshoppers grew bigger and bigger. As they grew larger, they ate so much that the children had to bring in fresh food from the meadow to supplement the food in the container. The third grade teacher did not know about this previous experience because this school did not keep a cumulative record file of the children's science experiences, and the course of study they were using did not include this kind of experience for second-graders.

Now, they are third-graders and have this related inquiry: What kind of food does this caterpillar need? The children and the teacher used a trial-and-error approach. Each day the children brought in different kinds of leaves. The caterpillar refused to eat. Several days and then a weekend passed. When the children returned to school on Monday, the caterpillar was dead.

This teacher may not have known much about insects, but did believe in honest group appraisal, and used questions similar to those listed in Table 4.3. These are some of the children's conclusions.

> We did not answer our question. The caterpillar died. We could have looked in a book to find out what kind of caterpillar we had. The book would have told what to feed it. We could have asked the second grade teacher, who knows a lot about caterpillars. We could have asked Dick where he found the caterpillar. Remember where we got the food for the grasshoppers we had in our room last year. Maybe the caterpillar was living near its food.

Both the children and the teacher discovered in this evaluation period that they had learned several important things about problem solving. They realized that they had rushed into answering the question without knowing the particular needs of this kind of insect and without realizing that the caterpillar might not live long enough for them to discover the food it would eat. They had learned that they needed to consider all known methods of attack because one might be more effective in answering their question than all the others. They had learned that time is a very important factor in scientific inquiry. They had remembered, unfortunately too late, that their school community had sources that they could use to help them answer their questions. They had also learned that caterpillars live in a certain kind of plant community and feed on certain kinds of plants. Perhaps the very dramatic way in which their experiment failed helped these children develop a better understanding of the interrelationships that exist in plant and animal communities than they might have had if their experiment had succeeded.

Children can be guided to evaluate their own ability to pursue advanced inquiries by a teacher who asks them questions and modifies the questions so that they can be used either with the group or with an individual child. (See Table 4.3.)

The questions below are intended to help the teacher screen the class for those children who want to probe, or who are already probing, further into an area. They also serve to inform the children that the teacher is willing for them as a class, as a small group, or as individuals, to pursue advanced inquiries.

Jackie was reported by the new student teacher in his room to be very uncooperative in his art class. Every child in the room was working on something for a Thanksgiving mural; that is, every child except Jackie. The strange wiggles and forms he was putting on his paper looked like crazy doodling to the student teacher. To be sure, Jackie sat pondering the forms on his paper. He was withdrawing from the group. He was daydreaming in a private world of his own. His own teacher sat down beside him and quietly

Group	Individual
What other inquiries in this area do we as a *class* want to explore ?	What other inquiries in this area do you want to explore ?
How many of you want to continue to work on more advanced inquiries in this area ?	On what other inquiries in this area are you still working ?

said, "Jackie, that looks interesting! Won't you tell me about it?"

Jackie, startled out of his deep "dream," replied, "Sure! I'm still working on that doorbell circuit. See! Here's the bell, the dry cell, and the switch. This is the wire and these little things are the electrons going through it. I close the switch and the electrons flow. The bell rings. I open the switch and the electrons stop. They stop at this space. There is a space here, too." Jackie pointed to the space between the battery terminals and continued, "I wanted to know what the electrons do here. Now I think I know." Jackie traced his finger along the wiggly lines that followed a wire to the outside terminal of the dry cell. From this terminal, Jackie had drawn wiggles down through the outside wall to the bottom of the cell, across the bottom to the center, and then up to the center terminal. "This," he said, "is where I think they go; down in and up out; not across the space."

Six-year-old Jackie was doing some abstract thinking. He questioned the validity of a science learning: electrons travel in a closed circuit or path. Unless he could figure out how the electrons got from one terminal to the other, the circuit to him would not be closed. Jackie had identified himself so closely with this inquiry that it consumed all his time and thought. The paper and crayons, together with the art time, seemed to him just the things he needed to help him solve this puzzler.

If the group, including Jackie, had been asked the two questions concerning the pursuit of further inquiries, Jackie might not have been in the dangerous position of being called uncooperative by the student teacher.

Junior, a sixth grade boy, was also very interested in science. He usually made good contributions in every class. This day, he was far off in the clouds. The teacher did not call Junior back from his "dream world," but waited until the children were leaving the room for home. Then he went back and sat down near him. "Junior," he said, "I missed your help today. What were you thinking about?" "I was thinking all right! Those theories about the solar system are just theories, aren't they? I don't believe them. I think I have a theory too! Can I tell it to the class tomorrow?"

Here were two nonconformists, a six-year-old and an 11-year-old, and two teachers who took the time to investigate, to show their interest, and to give encouragement to children who were probing more deeply than the rest. If Jackie and Junior had been asked—"Are there any more questions in this area on which you would like to work? Are you now working by yourself on any other inquiries in this area?"—the teachers might have been aware that they were not daydreaming but were taking much needed time to think out the answers to problems that were very real to them.

Techniques for evaluating children's progress in the development of desirable attitudes in terms of child behavior

A child's observable behavior is one key teachers have to his attitudes. Teachers can make a list similar to that in Table 4.4, including what they believe are the behavior traits indicative of desirable scientific attitudes and can use this list (1) to check each child's behavior and (2) analyze the strengths and weaknesses of the group or of individual children. They can also observe changes in attitudes. Additional date columns can easily be added to record successive checkings.

Not all the attitudes may be observed in every child or in the class during the study of every science inquiry. If the teacher is aware of what to watch for, he will be able to observe changes in children's attitudes which are evidences of their growth or progress. A single evidence of the presence or absence of these attitudes has little merit. A number of instances are needed to indicate a trend. Evaluation needs to be based upon consistent behavior. To be most effective, this kind of evaluation should be made about four times during the year or should parallel the period for reporting children's progress. Successive checkings should reveal not only whether the child makes progress in developing these attitudes but also whether the experiences provided by the teacher are effective.

Keeping records

Among the evidences which are real clues to children's progress, thinking, and behavior are treasures that a teacher might well record for himself. Many of these are the delightfully original things children say or do which make teachers go home at night feeling that teaching children is a most rewarding experience. If a teacher chooses

Table 4.4

ATTITUDES IN TERMS OF CHILD BEHAVIOR

Likes and Prefers to:	Date	Date
read science books		
read science magazines		
read scientific articles in the newspaper		
read about scientists		
read about inventions		
read science fiction		
make collections		
play science games		
own science toys		
own science equipment		
see science TV programs		
see science films		
go to science fairs		
go to museums		
go to planetariums		
go on science field trips		
Does:		
pursue science hobbies		
experiment		
plan experiments		
plan original experiments		
suggest plans for exploring inquiries		
construct science equipment		
construct science models and charts		
try to invent		
participate in science fairs		
use correct vocabulary		
try to predict what will happen on the basis of his previous learnings		
observe the world around him		
theorize		
do independent research		
avoid jumping to conclusions		
seek proof		
understand and use controls		

	Date	Date
talk about scientific things and events		
report on scientific news		
ask good science questions		
detect difference between truth and fiction		
persevere in methods of inquiry and research		
apply his science learnings to new situations		
see relationships		
Believes in and Practices:		
the scientific method		
causal relationships		
using more than one resource		
repeating experiments to validate his results		
questioning his results		
checking his results		
consulting authorities		
debunking superstitions		
Willing to and Does:		
change his opinion if sufficient evidence warrants it		
admit mistakes and try to correct them		
admit he doesn't know		
give credit to others when credit is due		
accept the possibility of error in available resources		
make allowance for human error		
criticize and evaluate his own work		
contribute ideas		
accept responsibility		
believe in scientific progress		
believe in the future of science		

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to make a permanent anecdotal record of these delightful things in a notebook or on a roll of magnetic tape, these records will become prized personal treasures. One teacher who does this has labeled a notebook and roll of tape with the word "dividends."

John Hall, age 7, Grade 1 Date ________

Last week the children in my class watched baby chicks being hatched in the incubator.

This morning, John came into the room bursting with excitement. "My mother's gone to the hospital to get our baby out!" he said. "How nice," I replied, "will she be home soon?" "I don't know," he answered, "I don't know how long it will take the baby to get out."

Henry Arthur, age 7, Grade 2 Date ________

After two days' absence, Henry returned this morning with his arm in a cast. "I fell

> from the apple tree," he explained. "Did you think you could fly like a bird?" I asked. "No," he said seriously, "gravity did it." Henry had learned that gravity caused things to fall and was applying his concept of causal relationships to a new situation.
>
> Walter James, age 5, Kindergarten   Date ________
>
> That 16 means "old" to a child of five, whose concept of time is still undeveloped, was proved today in our class. We had grown some tree seedlings in the room, and the children were wondering how long it would take to grow a big tree. Walter insisted the big tree in the schoolyard was there when his father came to this school. "My dad's 16," he said, "that tree's awfully old!"

If each child does not have the same number and kinds of science experiences, and if the same science experiences are not given at the same grade level every year, some kind of record keeping is essential. The *class, student,* or *teacher form* suggested here is designed for use with the inquiries listed in Part Two in this book.

Class record blanks like those in Table 4.5 can be mimeographed and a supply kept on file in the school office where teachers may obtain additional copies as they are needed. This record form requires a minimum amount of bookkeeping. It takes the teacher only a few seconds to check the inquiries which the grade has explored. This sheet should be included in the class file of cumulative records and sent with the children when they are promoted. When the children work again another year in the same area, the new inquiries which are explored can be checked on this same sheet.

Individual pupil records also can be valuable. Some schools may want to do this because they are emphasizing maximum individual growth or because the pupils in a group change greatly during the period children attend elementary school. These pupil record sheets can also become a part of the child's permanent school file. Some schools might consider a class record to be more economical, with individual records being made for only those children who work more slowly or more rapidly than the group. (See Tables 3.3 and 3.4.)

Teachers and administrators can also obtain valuable information about the children in their school system if teachers keep a record over a period of years of the inquiries explored with children on each grade level. (See Table 4.6.) This record would provide concrete evidence of the inquiries in which children in a specific grade are interested and of any changes in interest that occur over a period of years.

Still another kind of record might be valuable. Under each inquiry in Part Two, one or more experiences have been suggested. You will have opportunities to add to these. If children are encouraged to test their ideas about how an inquiry can be explored, they frequently suggest something very original. This kind of creative thinking gives children a feeling of satisfaction.

Table 4.5

CLASS OR STUDENT RECORD OF INQUIRIES INVESTIGATED

Area (to be filled in by teacher):

Inquiry Number from Text	Kindergarten	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
1							
2							
3							
4							
5 . . . , etc.							

Make a record of these experiences on a filing card.

How many teachers would ever think of giving artificial respiration to a fish? A child did! This is a copy of the card the teacher made of this experience.

> AREA: How Are Plants and Animals Alike?
> INQUIRY NO.:
>
> Artificial Respiration for Goldfish
>
> Blow *air* (not exhaled gases from lungs) through a straw into mouth of goldfish.
> Goldfish must *be in water* when this is done.
> The children revived a goldfish this way, today.
>
> May 8, 1970

Experiences, such as the one described, mean much to children. At the same time that this kind of experience gives children the thrill of discovery, it gives the teacher the thrill of watching children think. The very act of putting this experience on file for future use means that the teacher has judged it an example of original problem-solving techniques. The act also implies that the teacher has evaluated the children who created the experience.

Table 4.6

TEACHER'S RECORD OF INQUIRIES INVESTIGATED

Area (to be filled in by teacher):

Inquiry Number from Text	1970	1971	1972	1973	1974	1975
1						
2						
3						
4 . . . , etc.						

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Chapter Five

Science Materials

Many of the "who, what, why, when, where, and how" questions that children ask are stimulated by their curiosity about the *things* in their environment: the common things in the classroom, the school, the schoolyard, the home, and the community. Such things as egg beaters, teeter-totters, alarm clocks, sprouting seeds, drinking fountains, clouds, elevators, door bells, telephones, radios, televisions, tape recorders, doors that open electronically, hinges, door locks, pencil sharpeners, and so on, are typical of the things about which children are curious. Worthwhile science experiences can utilize these materials which are available to all teachers.

In the same sense that the *things* in the children's environment are science *materials to explore*, the classroom, the school, the schoolyard, the home, and the community are the children's *science laboratories*. Under ideal conditions, children can always be taken to the places where the material is available. When the children wonder about seeds, how they grow, and the conditions they need for growth, they should be able to observe and experiment with plants in the garden or field. When they want to see the mountains on the moon, or the rings of Saturn, they should be able to view these bodies through a telescope. When they want to discover how electricity is produced, they should be able to visit the city power plant. It is usually possible for children living in small cities and villages to take advantage of these first hand experiences. In larger cities, the transportation problems, time, and distances needed for getting to these places make it difficult for the whole community to be utilized as a laboratory.

Because, even under ideal circumstances, it is impossible for children to observe and manipulate all science materials in real life situations, the classroom and its immediate environs play an important role in providing laboratory experience. The responsibility for bringing into the classroom the part of the child's environment that cannot be directly observed in its natural setting falls upon teachers and administrators.

When elementary science was in its infancy, it was assumed that the classroom teacher's need for materials would be so limited and infrequent that he could borrow the few materials he needed from the junior or senior high school science laboratories or from the community. Junior and senior high school science departments, however, usually operate on an equipment budget that is too limited for their own needs, and therefore, they cannot meet additional demands for equipment from the elementary school. Therefore elementary schools must assume responsibility for organizing a science program and for including in the annual budget the money necessary to support this program.

There was a time, also, when it was advocated that classroom teachers depend for their science materials upon local contributions, borrowed equipment, homemade apparatus, and teacher- and child-made collections. For some of these materials, these sources may still be utilized. Homemade equipment, especially if the children can construct it, often serves the purpose better than the commercial kinds. The necessity to depend solely upon these sources is frustrating, however, and can represent a poor use of time for both teacher and child.

Prior to passage of the National Defense Education Act, a number of school systems allocated very little money in the annual budget for the elementary school science program. The NDEA. makes it possible for schools to receive a reinbursement of 50% of the cost of *approved* materials and equipment. If your school system has not utilized the opportunity offered by the NDEA, obtain the approved equipment list, which is available from the U.S. Department of Health, Education, and Welfare, Office of Education. Discuss with your administrators the possibility of augmenting your annual science budget with these federal funds.

Science equipment and supplies are essential to the development of a good elementary science program. There are many experiences that children need which cannot be provided without adequate equipment and visual aids.

How to select equipment

What kinds of materials and equipment do children need to stimulate their curiosity, broaden their interests in their community, and provide them with the basic understandings necessary to meet their individual and group needs? The following are some basic criteria that should be met when selecting material and equipment for elementary school science:

1. Must be appropriate to the learning situation;
2. Should stimulate an inquiring attitude;
3. Should be easy to manipulate;
4. Should be safe for children to use;
5. Should be chosen on the basis of the way in which they are to be used (larger pieces of equipment are needed for demonstration than are needed for individual and group work);
6. Should be durable and accurate;
7. Should be built so that they can be disassembled, whenever possible;
8. Should expand interest and facilitate ways of working toward specific goals.

Because currently there is such a wide variation in the science background of children in different communities and because there is no set pattern for grade placement of science concepts, determining what kinds of basic materials are to be provided for their school becomes a local problem for the faculty and administrators.

As a first step, each teacher in the school might list the equipment that he considers necessary to solve the inquiries in the science areas assigned to his grade, and also what equipment he thinks he may need for the incidental inquiries that arise. For example, experience with children indicates that the teacher should be prepared to house, if only temporarily, almost any kind of small animal. Keeping and studying small animals may be part of the planned program, but, as all teachers know, animals may arrive at unexpected times.

The next step would be for the administrator or a small committee of teachers to compile the lists made by individual teachers. This summary should group together the same kinds of materials and determine the quantity needed for the school. Catalogues from scientific supply houses (page 57) can be consulted for stock numbers and sizes. A high school science teacher or science consultant can help the committee with sizes. It is easy to be confused by the great number of different sizes listed for the same article. Prices are not always given, and if they are, are subject to frequent changes. However, an order can be submitted to the science supply house for a price quotation. When the quoted price is received, the committee through the administrator can present it, together with the requested list of equipment, for approval in the school budget. Most administrators and boards of education act favorably on such a request, because a faculty group is saying in a professional way: "This is the science equipment we need in order to give the children in our school the kind of science experience we believe they should have."

There are several reasons why one person should be responsible for the final ordering of the science materials for the school or the school system. A composite school order is larger, and science supply houses quote better prices on larger orders. Even though you may be combining your order only with the orders of the other teachers in your school system, you can still realize this price advantage. Also some things, such as chemicals, glass tubing, etc., cannot be bought in small quantities.

Here are several points to keep in mind and some useful hints in ordering equipment and supplies for your school:

1. Write to some of the supply houses listed later in this section, state that you are responsible for ordering science equipment and supplies for your school and that you would like copies of their catalogues. Certain supply houses charge a nominal amount ($1–$2) for a catalogue. This amount will be refunded to you when you place an order.

2. If you are unfamiliar with science equipment and supplies, make a tentative list of materials desired, noting the catalogue and page number of the item. Then ask a science teacher or consultant to advise you regarding the suitability, size, quantity, and quality. Order such items as magnets, magnetic compasses, prisms, magnifying glasses, mirrors, and motors large enough for children to handle and observe easily. Buy thermometers (Fahrenheit and centigrade) that have red liquid in the bores. The red color can be seen from a greater distance and helps the children to read thermometers with a greater accuracy. Consider the *safety factor* when ordering glassware. Pyrex glassware is more expensive, but if it is properly handled, it can be placed directly over a flame. Milk bottles and soft-drink bottles would shatter if given this kind of treatment. Before Pyrex glassware can be placed directly over a source of heat, it should be carefully dried and the bottom of the container should be warmed slowly by holding it above the flame and moving it back and forth across the source of heat for a few seconds.

3. The yearly expenditure for dry cells can be greatly reduced by the purchase of six-volt, direct current battery substitutes or rectifiers. A battery substitute steps down the voltage from 110–120 volts to six volts and changes the current from alternating to direct. Try to purchase battery substitutes that have a rheostat and switch. The rheostat controls the amount of electricity flowing in the circuit and the switch eliminates the necessity of disconnecting the wires from the device when it is not in use. Any child who knows how to operate an electric train transformer can use the rectifier safely and will know how to wire it in the circuit. Dry cells are a necessity in some of the experiments children do in their work with magnetism and electricity. Dry cells are also better for the younger children to use.

4. Select the simplest material you can find for the purpose intended. If well constructed and if the same principle is illustrated, children's toys are preferable to commercial types of equipment.

5. Whenever possible, order equipment that can be dismantled, so that children can discover how it is constructed and what makes it work. If the equipment selected cannot be dissembled and reassembled, buy duplicates so that the children can take one apart and examine it.

6. Select good quality tools, such as geological hammers and carpenters' tools. They may cost more, but in the long run, they will more than pay for themselves. The heads of cheaply constructed hammers are likely to "fly off" at the wrong moment. Inexpensive knives and screw drivers break easily. Cheap metal cutters leave

jagged edges on the metal. *Valuable lessons in safety* can be taught while the children are learning to handle tools properly. Well constructed tools also help encourage children to give them proper care.

7. Before placing your order with a scientific company, visit local stores and see how many items on your list can be purchased from them.

8. Each year try to buy at least one piece of permanent equipment, or a teaching collection that will be valuable in increasing the scope and effectiveness of your science program. Such materials can be acquired over a period of years if the budget does not permit their immediate purchase. Some schools, operating on very limited budgets, are managing gradually to buy these items. In some cases, parent-teacher associations make annual contributions for the purchase of certain pieces of equipment. In a few instances, school children have raised the money and donated the equipment to the school. These seem like devious ways of obtaining materials essential for the science program, but they are possibilities. An adequate annual budget for science, together with cooperative planning in its expenditure, is a more effective and efficient means for obtaining the equipment, materials, and supplies which a faculty needs for helping children with science. The annual science budget should also allocate funds for the repair of equipment and for the replacement of consumable and perishable items.

The initial purchase of equipment for the school may not provide everything that will eventually be needed. If the procedure suggested is followed for a few years, however, a school can accumulate a fine selection of equipment which is really practical for use in the elementary school. As the teachers and children use the equipment, they will grow in their ability to select and use additional items. *Buy what you will use and then use what you have bought.*

When the equipment order arrives, especially if it is the first, the complete order should be displayed for all teachers and children to see. Parents, too, are interested in the materials their children are going to use and will appreciate having the equipment shown at a PTA meeting.

An inventory book should be set up, using the order as a guide, so that each item is listed, followed by its catalogue number, size, quantity, and price. Then the equipment can be handled as your faculty decides. It may be distributed to the individual teachers who ordered equipment. Or it may be more practical to have the equipment arranged in a convenient closet or supply space, which is designated as the *science equipment supply room.* This makes all science equipment available to every teacher and group of children. Materials used only occasionally, which are too expensive to duplicate for each grade or are not safe to store in the classroom, should always be stored in the science equipment supply room. *Never store chemicals in a classroom;* always store them in a separate cupboard or closet away from other equipment in the science equipment supply room. All chemicals should be kept in *airtight* containers that are *clearly* and *correctly* labeled.

Whether a formal loan system is needed depends upon the size of the school. If the school has 25 classrooms or fewer and the equipment is used only in that school, a teacher need not take long to find out who is using a piece of equipment that is not in the science equipment supply room. If necessary, it should not be too difficult to organize an equipment loan system, similar to the loan systems used by school libraries; however, in this case, one person must be responsible for checking the equipment in and out, for keeping the inventory, for keeping the materials in repair, and for replacing and replenishing them. In some school systems, teachers share this responsibility on a weekly basis and have some of their children assist them. In other school systems, a teacher is paid extra for this special service.

If the equipment is divided and is kept in the classrooms, lack of storage space for these materials can be a serious problem. Some teachers have learned that both time and space are saved if the materials used in a certain area of science, such as magnetism, are packed in well labeled cardboard boxes. If there is no cupboard space for them, boxes that are uniform in size can be stacked like a filing cabinet and placed in the science equipment supply room or in some out-of-the-way corner of the classroom. The children can cover the boxes with finger paintings or decorate them attractively.

Because some school systems lack classroom storage space and a well organized science equipment supply room, they have purchased the all-in-one commercially assembled science kits. Some of these kits are excellent, but many are much too costly and limited in scope. It is much cheaper for a school system to buy science materials in quantity and to distribute them to the classrooms and science equipment supply room on the basis of interest and need.

Before budget time each year, all equipment should be called back to the science equipment supply room for one day and checked against the inventory. At this time it is fairly simple to start the next year's equipment list with those items which need replenishing or replacing and those which the original order did not supply in sufficient quantity. Some supplies, such as chemicals, batteries, glassware, and so on, are considered consumable and must be replenished yearly.

Because most school budgets are made out in the spring for the school year that begins the following fall, it is not always possible to foresee exactly every item which may be needed. Therefore, an ideal science budget, in addition to a request for the purchase of an itemized list of materials, contains a specific sum of money which can be spent by the school administrator for unforeseeable science needs when the occasion arises.

SCIENTIFIC SUPPLY HOUSES

A. I. Root Company, Medina, Ohio, 44256.
A. J. Nystrom and Company, 333 N. Elston Ave., Chicago, Ill., 60618.
American Seating Company, 923 W. Genesee St., Syracuse, N.Y., 13204.
Bausch and Lomb Optical Company, 626 St. Paul St., Rochester, N.Y., 14602.
Cambosco Scientific Company, 37 Antwerp St., Brighton Station, Boston, Mass., 02135.
Cambridge Botanical Supply Company, Waverly, Mass., 02179.
Carolina Biological Supply Company, Elon College, North Carolina, 27244.
Celestial Map Publishing Company, 244 Adams St., Brooklyn, N.Y., 11201.
Central Scientific Company, 1700 Irving Park Road, Chicago, Ill., 60613.
Criterion Manufacturing Company, 331 Church St., Hartford, Conn., 06103.
Denoyer-Geppert Company, 5235 Ravenswood Ave., Chicago, Ill., 60640.
General Biological Supply House, 8200 S. Hoyne Ave., Chicago, Ill., 60620.
Jensen Manufacturing Company, Jeannette, Pa., 15644.
Ken-A-Vision Manufacturing Co., Inc., 5615 Raytown Road, Raytown, Missouri, 64133.
Macalaster Scientific Corporation, Dept. SC-4, 186 Third Ave., Waltham, Mass., 02154 (Macalaster AAAS Catalog of Equipment Kits).
Products Design Company, Science Education Division, 2796 Middlefield Road, Redwood City, Calif., 94061.
The Radiac Company, Inc., 489 Fifth Ave., New York, N.Y., 10017.
Science Associates, 194 Nassau St., P.O. Box 216, Princeton, N.J., 08540.
Science Materials Center, 59 Park Avenue South, New York, N.Y., 10003.
Science Research Associates, Inc., 259 E. Erie St., Chicago, Ill., 60611 (Learnings in Science Laboratories—Kits).
Stansi Scientific Company, 1231–41 N. Honore St., Chicago, Ill., 60622.
Wards' Natural Science Establishment Inc., P.O. Box 24, Beechwood Station, Rochester, N.Y., 14609.
W. M. Welch Scientific Company, 1515 Sedgwick St., Chicago, Ill., 60610.

How to select films

Science movies and filmstrips are valuable teaching aids. Many excellent 16mm sound motion pictures have been produced in the area of elementary school science. Some school systems buy films and build a local film library. This is an ideal arrangement because the teacher can obtain any film she needs with a minimum of delay. Other school systems prefer to rent films from the nearest rental library. Because of the great demand, it is often necessary to place film orders with these rental libraries months in advance of the date when the films are to be used. Such advance ordering makes it difficult to plan for the arrival of a film at the time when it can provide its maximum educational value as a teaching aid. However, careful planning by the teacher can minimize this disadvantage.

The following companies have produced many films in the area of elementary school science. Write for their 16mm sound motion picture catalogues. Each film will be well described in the catalogue to help you or your visual aids committee select the films you wish for your grade or your school. If you are planning to purchase the film, arrange to preview it before making your final decision to buy.

SOURCES OF 16MM SOUND FILMS

Churchill-Wexler Film Productions, 801 N. Seward St., Los Angeles, Calif., 90038.
Coronet Films, Coronet Building, Chicago, Ill., 60601.
Encyclopaedia Britannica Films, 1150 Wilmette Ave., Wilmette, Ill., 60091.
Film Associates of California, 10521 Santa Monica Blvd., Los Angeles, Calif., 90025.
International Film Bureau Inc., 6 N. Michigan Ave., Chicago, Ill., 60602.
March of Time–Forum Films, 369 Lexington Ave., New York, N.Y., 10017.
McGraw-Hill, Text Film Department, 330 W. 42d Street, New York, N.Y., 10036.
Moody Institute of Science, Educational Film Division, 11428 Santa Monica Blvd., Los Angeles, Calif., 90025.
Sterling Films, Inc., 316 W. 57 St., New York, N.Y., 10019.
Teaching Film Custodians, 25 W. 43d St., New York, N.Y., 10018.
United World Films, 1445 Park Ave., New York, N.Y., 10029.
Walt Disney Productions, 477 Madison Ave., New York, N.Y., 10022.
Young America Films, Inc., 18 E. 41 St., New York, N.Y., 10017.

A good film rental library has most of the film titles listed by the producers in the preceding list. Send to the film rental sources in your area for their catalogues of 16mm sound motion pictures. Many universities, museums, and state education departments have film rental libraries. Their catalogues also contain a description of each film title to help you with your selection.

The following film companies have produced filmstrips in the area of elementary school science. Write to them for their catalogues. Filmstrips are more commonly bought than rented. Your visual aids committee should preview all filmstrips before they are purchased to determine whether they are likely to be valuable teaching aids for your elementary school science program.

SOURCES OF FILMSTRIPS

Charles Scribner's Sons, 597 Fifth Ave., New York, N.Y., 10017.
Children's Reading Service, 1078 St. John's Place, Brooklyn, N.Y., 11213.
Curriculum Materials Corp., 1319 Vine St., Philadelphia, Pa., 19107.
Educational Audio Visual, Inc., 57 Wheeler Ave., Pleasantville, N.Y., 10570.

Encyclopaedia Britannica Films, Inc., Filmstrip Division, 1150 Wilmette Ave., Wilmette, Ill., 60091.

Eye Gate House, Inc., 146 Archer Ave., Jamaica, N.Y., 10035.

Filmstrip House, 432 Park Ave. South, New York, N.Y., 10016.

Jam Handy Organization, Inc., 2821 E. Grand Blvd., Detroit, Mich., 48211.

Life Magazine Filmstrips, 9 Rockefeller Plaza, New York, N.Y., 10020.

Resources for Education, Inc., 63 Fourth Ave., Mount Vernon, N.Y., 10550.

Society for Visual Education, Inc., 1345 Diversey Parkway, Chicago, Ill., 60614.

Stanley Bowmar Co., 12 Cleveland St., Valhalla, N.Y., 10595.

Young America and Popular Science Filmstrips, Text-Film Department, McGraw-Hill Book Company, Inc., 330 W. 42d Street, New York, N.Y., 10036.

How to select textbooks

Every classroom should have science textbooks for the children to use. The philosophy of the local school system determines which of the following plans is chosen for the purchase of science textbooks. Some school systems adopt a science textbook series and buy a book of the selected series for each child in each grade. Other school systems build a science textbook library for each grade by selecting five, six, or more of the different textbook series. Every grade is then supplied with about six copies of each of the textbooks selected. The schools that purchase books this way believe that each child, in the course of the year, will read not one science textbook, but as many as are available in the room. This method of purchasing textbooks for each classroom (six of each series) tends to keep the library up-to-date at less expense and to provide a wide variety of science reference material.

How to select science library books

In addition to a textbook library, every classroom should have access to the many good children's books available in the major areas of science. There are literally hundreds of these science books from which to choose, and among them are books of interest to pupils at every level of reading ability.

Schools make these books available to the classroom in a number of ways. They may buy for each classroom those books which complement the science program of that grade and are on an interest and reading level appropriate for the grade. If the elementary school has a children's lending library, science books may be bought for that library, or for a central curriculum library. The books can be arranged as small supplementary science libraries (12 to 15 different books in one science subject area), which the classroom teacher can order on a loan system to use during the study of a certain science area.

The best way to keep up to date on the newest of these publications is to have a standing library book committee which, at least once a year, reviews and prepares a recommended list of books for the teacher to use in selecting new classroom library books.

SCIENCE BOOKLISTS

American Association for the Advancement of Science, "The Science Book List for Children." Washington, D.C.: 1515 Massachusetts Ave., 20005.

American Library Association, "The Booklist." Chicago: The Association, 50 Huron St., 60650.

American Museum of Natural History, "Man and Nature Publications." New York: The Museum, 77 Street and Central Park West, 10024.

Association for Childhood Education International, "A Bibliography of Books for Children." Washington, D.C.: 1200 Fifteenth Street, 20016.

Board of Education of the City of New York, Bureau of Curriculum Research, "A Selected Bibliography in Elementary Science." New York: Curriculum Center, 130 W. 55 St., New York, N.Y., 10019.

Bureau of Elementary Curriculum Development, "The World of Science." Albany, N.Y.: New York State Education Department, 152 Washington Ave., 12210.

"Children's Catalogue with Annual Supplements." New York: H.W. Wilson Co.

Hall, Elvajean, "Basic List for Elementary School Libraries," Vol. 1, No. 1, September 1954; Vol. 1, No. 2, October 1954.

Mallinson, George G., and Lois M. Mallinson, "A Bibliography of Reference Books for Elementary Science." Washington, D.C.: National Science Teachers Association, 1201 Sixteenth St., N.W., 20036.

National Aeronautics and Space Administration, Educational Service Bureau, pamphlets and photographs on weather, space explorations, and rockets. Washington, D.C., 20025.

National Audubon Society, "Nature Program Guide: Guides to the Outdoors." New York: The Society, 1130 Fifth Ave., 10028.

National Education Association, Association for Supervision and Curriculum Development, "List of Outstanding Teaching and Learning Materials." Washington, D.C.: The Association, 1201 Sixteenth Street, N.W., 20036.

New York State College of Agriculture, "Science Books for Children," Department of Rural Education *Leaflet*, Vol. 51, No. 1. Ithaca, N.Y.: Cornell University, 14850.

Piltz, Albert, "Science Publications: An Annotated Guide to Selected Listings." Washington, D.C.: U.S. Department of Health, Education, and Welfare, Office of Education, 20036.

Science Curriculum Improvement Study, Dept. of Physics, University of California, Berkeley, Calif., 94720 (*News Letter:* free on request, subscription).

Time-Life Books, 4200 N. Industrial Blvd., Indianapolis, Ind., 46254.

ADDITIONAL READING

Beuschlein, Muriel, "Free and Inexpensive Learning Materials," 12th ed. Nashville: George Peabody College for Teachers, Division of Surveys and Field Services, 1964.

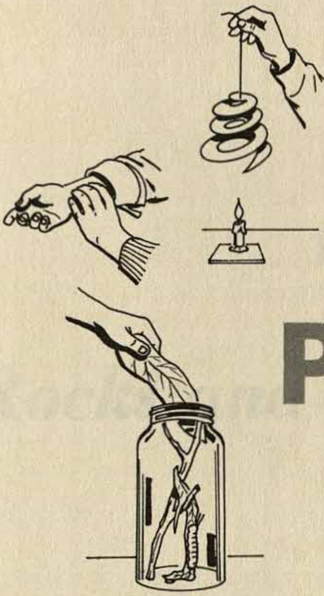
Gantert, Robert L., "Science Kits as Classroom Aids," *Laboratories in the Classroom.* New York: Science Materials Center, 1960, pp. 87–88.

Lange, Erwin F. and K. E. Payne, "Science Kits in Elementary Science Teaching," *The Science Teacher,* 25, 6 (Oct., 1958), 321–23.

"New Line of Classroom Kits to Aid Teachers Without Science Training," *Teacher Topics,* I, 1 (Spring 1962), 1–3.

Piltz, Albert, "Getting the Most from the Equipment Dollar," *The Instructor,* No. 73 (Jan., 1964).

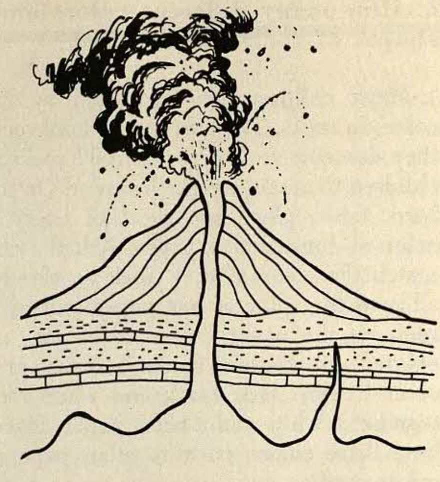
Zafforoni, Joseph and Edith Selberg, eds., *New Developments in Elementary School Science.* Washington, D.C.: National Science Teachers Association, 1963.



Part Two

S.C.E.R.T., West
Library
Calcutta
25/3, B. C. Roa

Chapter Six



The Earth's Rocky Crust

Rocks and Minerals

INQUIRIES

1. How many different colors and shapes of rocks can we find?
2. What words can we use to describe how rocks feel?
3. How can the shapes of rocks be changed?
4. What are some of the natural forces which cause rocks to have different shapes?
5. Why do rocks have different colors and textures?
6. How are minerals identified?
7. What are rocks? How are rocks classified?
8. Which rocks are igneous? How can igneous rocks be identified?
9. How are igneous rocks formed and distributed?
10. Which rocks are sedimentary? How can they be identified?
11. How are sediments deposited and changed into sedimentary rocks?
12. Which rocks are metamorphic? How can they be identified?
13. How are metamorphic rocks formed?

1. How many different colors and shapes of rocks can we find?

Many children are fascinated by the varied colors in rocks. They bring to school rocks, which they describe as "pretty-colored" rocks. Help the children to arrange rocks by color. On the science work table, place one sheet of every available color of construction paper. Ask the children to match the color of each rock as closely as possible to the color of one paper and to place the rock on the paper. Some rocks may be multicolored and contain bands, streaks, or flecks of several colors. For black and white rocks, paste together a white and a black paper. If some rocks have three colors, paste together papers of three colors, and so on.

When the children have matched the rocks to colored papers, discuss the colors they have seen in the rocks. Young children will see and name black, white, gray, brown, red, pink, purple, green, and so on. They will classify some rocks by one color and others by two or more colors.

Borrow rocks that children can handle from the school collection. Ask the children to find out if any rocks in their classroom collection match rocks in the school collection. Collect rocks with many different shapes. Have the children arrange together rocks with similar shapes. Collect rocks that are round, oval, triangular, square, rectangular, as well as rocks of no particular geometric form. Make paper cutouts to resemble these shapes, label the cutouts with a word describing the shape, and use these labels with rocks of similar shapes.

Take a field trip to collect additional rocks. The trip may be to the playground, the park, a gravel pit, a garden, or a stream. If there is a science museum in your school or community, make arrangements to go there to look at the rock collections.

2. What words can we use to describe how rocks feel?

Have the children rub their fingers on rocks, rub rocks on their cheeks, and so on. Ask them to describe how the rocks feel. They may use some of these descriptions.

DESCRIPTION	FOR
Smooth	Shale, slate, limestone, marble
Slippery	Talc, soapstone, schist
Rough and jagged	Granite, syenite, quartzite, gneiss
Gritty	Sandstone

Help the children to understand that the rocks *feel* different because their *texture* is different. Introduce the word texture. Discuss its meaning and provide opportunities for children to add it to their working vocabulary.

Borrow the school's rock collection. Have the children test and describe the texture of each rock. Perhaps the building custodian or the superintendent of buildings and grounds will take you and your children on a trip through the school to see and feel the stones used in the building's construction. These are some of the stones they may be able to see and feel.

OBJECT	MATERIAL
Chalkboards	Slate
Sinks	Soapstone
Walks, steps, walls, floors, trim, etc.	Granite, marble, slate, brick, concrete, cement blocks, tile, terrazzo

Many of these stones will feel smooth but some, like the concrete, the cement blocks, and the bricks, will feel rough and gritty. Observe that some are *natural stones* and some are *synthetic* (*man-made*) *stones*.

This trip may motivate the children to make collections of natural and synthetic stone objects, which are used in their homes. Their collections of natural stone objects may include polished marble, granite, soapstone, slate, and the stones used in jewelry. The synthetic stone collections may consist of tile, brick, concrete, stucco, pottery, porcelain, chinaware, plaster, glassware, enamel, and granite ware.

Most of the objects in these collections will feel smooth, but some will feel rough and gritty. Call the children's attention to the inner and outer surfaces of pieces of broken pottery, tile, and chinaware. Ask them if they can think of any reason why manufacturers glaze so many of the surfaces of these articles. Plan an experiment to find out whether smooth or rough objects are easier to clean. (They will find that smooth surfaces are easier to clean.) After the experiment is finished, discuss the results. Apply this learning by finding out whether the children can think of a reason why health and sanitation departments forbid the use of chipped and cracked dishes in public eating places. (Food particles and disease-causing organisms cling to the rough places in the chips and cracks.)

3. How can the shapes of rocks be changed?

Obtain a geological hammer or a well made carpenter's hammer, a piece of canvas or burlap, and a piece of heavy sheet metal. Show the children how to break several of the rocks in their collections. It would be well to plan to do this experiment outside. A sidewalk is a good place to work, but the concrete should be protected with the piece of metal. Teach the children how to use the hammer and discuss some of the safety precautions they should take when they break rocks. (The rocks that they are planning to crack should be covered with a heavy piece of cloth, canvas, or burlap to prevent rock fragments from flying and striking the children who are watching the experiment. The class should give the child who is going to break the rock enough room to swing the hammer.) Listen to the children's comments as they break the rocks. When they are finished, their remarks can be used to initiate a general discussion about what has been learned. Their summary may include findings like these: (1) Some rocks break easily. (2) Some rocks are hard to break. (3) Rocks break into every shape except round and oval. Ask them to discuss why the metal was used to protect the sidewalk. (If the hammer head strikes the concrete, the concrete may break or chip.) Ask them if they have ever seen men breaking up old concrete sidewalks or concrete street pavings with either sledge hammers or air hammers.

Save the fragments of rock from the previous experiment for further observation, experimentation, and for distribution to the children for their personal collections.

Give each child a few of the broken pieces of rock and a newspaper to protect the desk. Suggest that there may be a way to make the rough pieces rounder and smoother. Explain that *one rock should not be placed on the table and pounded with another because it would mar the furniture.* Do not give them any further instruction. If you watch, you will see them rubbing, scrubbing, and rolling the rocks. You will hear them exclaim when they discover that they are removing small grains, sediments, and fragments from the rocks. They will tell you that it is hard work to round and smooth the rough parts and edges of rocks; it will take years to polish the surfaces of rocks.

If your school has a collection of the stone axes and arrowheads used by Indians, let the children examine and handle them. The children will develop a better appreciation of the amount and kind of work that went into the shaping of these tools because they too have tried to shape rocks. Museums generally have a collection of stone tools, which you can take your children to see.

4. What are some of the natural forces which cause rocks to have different shapes?

Discuss why some rocks have rounded shapes. Where were these rocks found? (Round and oval-shaped stones are most likely to have been found on beaches, on the shores surrounding bodies of water, and on the bottoms of stream beds.) The children's discussion should establish some of these facts:

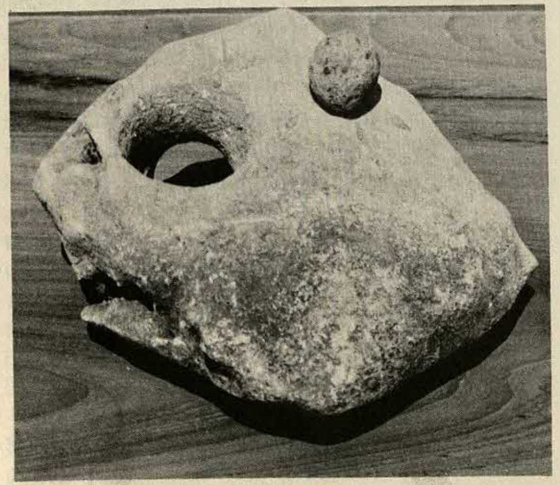
Swiftly moving waters in streams and waves dashing against the shore tumble rocks against each other, rolling, rubbing, scrubbing, grinding, and smoothing them into these shapes. Northern gravel deposits also are rich sources of round, oval, and triangular-shaped stones. *Glaciers* are huge masses of moving ice. As they move over the bedrock, they tear loose pieces of rock and drag these rock fragments along with them. Streams flowing from the melting glaciers also help to roll and round the rock fragments into shapes similar to those of rocks found near streams, lakes, and oceans. Long ago there were glaciers covering parts of Canada and the United States. The rocks in many northern gravel deposits were shaped by these glaciers.

Wash several small, irregular-shaped pieces of broken rock. (Because they are comparatively soft, sandstone, limestone, and shale are good rocks to choose for this experiment.) Have each child place two or more of the washed rocks in a glass jar, which is partially filled with water. Before the experiment is started, observe the water in the jars to be sure that it contains no small sediments from the rocks. Screw the lids on the jars very tightly and have the children roll the jars back and forth over several layers of cloth, which have been placed on the floor. Roll the jars many times. As the jars are being rolled, watch the rocks in the water tumble against each other. Compare this tumbling action of rocks in water to the action of water running in rocky stream beds and to the action of waves on rocky shores. Have the children watch the water for small rock fragments, particles of sand, and very fine silt.

Break an old brick into pieces about one inch square. Place the pieces in a glass jar of water and roll the jar as in the preceding experiment. Have each child roll this jar about 100 times. Observe the gradual change in shape that occurs. Compare the rounded brick fragments with the rounded rock fragments from the preceding experiment. Emphasize how long it must take for broken fragments of rocks to be worn into rounded shapes by the action of water.

Wash another piece of *soft* rock until it is free of loose sediment and place it in a large clean glass or enamel dish. (Sandstone is a good choice.) Pour water onto the rock so that the water *falls* from some height and hits the rock with some force. Examine the water in the pan. Notice whether the falling water causes some small particles to break loose from the standstone.

Fig. 6.1 Pothole in rock.



Look for places where the water draining from roofs repeatedly falls on driveways, sidewalks, and slate or concrete flagstones, or where rainwater drips from a tree limb. These places can easily be located on a rainy day. Examine the place where the falling water hits, for evidence that pieces of the surface have been broken and washed away. (There may be a depression in the surface at these places.)

Take a trip to observe the bedrock below a waterfall or dam. If the water is falling over the falls or dam, the children can see how it hits the rocks below. Observe that the bedrock below the falls or dam has been worn smooth by the falling water. Try to find potholes in this bedrock. (*Potholes* are round holes of various sizes and depths in the bedrock of rivers and streams.) (See Fig. 6.1.) If the running water in the stream or river brings a loose rock to a place where it gets wedged so that it cannot be carried father down river, the continual movement of the water may cause this rock to grind a depression in the bedrock. As this depression deepens, it becomes a pothole in which the rock fragment continues to grind away at the walls and bottom until the rock itself is completely ground into sediment. If the bedrock of the river is dry enough to explore, look for rocks in the bottoms of the potholes.

The class can make a small pothole by placing a piece of sandstone in a bowl of water and grinding and boring one spot on it with a smaller, harder rock.

Try to dry polish a piece of shale, limestone, or marble with different grades of sandpaper and compare the results with the effect of these same sandpapers on wood.

If possible, watch the machines that sand and polish wood, stone, and terrazzo floors. Sandblasting machines are also used to clean public monuments, and brick and stone buildings. Names and dates are engraved on memorial stones by sandblasting machines. Make an appointment with the manager of a monument sales place to see the sandblasting machine engrave stone. Children who live in regions where sandstorms are common may be able to visit places where wind-driven sand has polished, carved, ground, and reshaped rocks. They may have seen or heard how wind-driven sand can remove paint and scratch glass.

In areas where sandstorms do not occur, study colored slides, movies, or postal cards that show wind-carved rock formations. Someone in your community, who has traveled to the Southwest, may have some of these pictures and can be invited to show them.

Some of the following experiences are based upon the learning that "most solids expand when heated and contract when cooled." If your class has not learned this, provide them with the experiences in Inquiry 4, Chap. 9, so that they can discover it for themselves.

Discuss the temperature changes that occur between day and night and between summer and winter. Talk about the ways in which these changes in temperature may cause rocks to expand and contract. Plan experiments to show that temperature changes cause rocks to expand and contract. The class may suggest experiments similar to the ones that follow.

Make a plaster mold of a round pebble. Grease the pebble and coat it with a thick layer of plaster of Paris paste. The paste is made by mixing the plaster of Paris with water. When the mold has hardened, cut it in half with a sharp knife and remove the pebble. Heat the pebble until it is very hot. Remove it from the heat with tongs or a thick potholder. Try to fit the pebble into the plaster mold. (If the rock has been heated long enough, it will be too large to be fitted into the mold.) Wait until the pebble is cool and then try again to fit it into the mold. (It should fit.) Ask questions like these about the experiment. Why won't the hot pebble fit into the mold? (The hot pebble was too large; it expanded when it was heated.) Why will the cold pebble fit into the mold? (The cold pebble was smaller than the hot pebble; it contracted when it was cooled.)

Grease a flat, oval-shaped rock and heat it in a pan on a hot plate. Place a cake of paraffin in a cool metal pan. Remove the heated rock and press it into the cake of paraffin. Take the rock out of the paraffin when the paraffin begins to congeal. Observe the imprint of the rock in the paraffin. This imprint will be the same size as the hot rock. Clean the rock and let it cool, and then try to fit it into the paraffin mold again. (The rock will be smaller than its imprint in the paraffin.) What does this experiment show? (That the rock expanded when it was heated and contracted when it was cooled.)

Fill a milk bottle full of water; press the cardboard cap on tightly, and place the bottle in the freezing compartment of a refrigerator. If your school does not have a refrigerator, have a child do the experiment at home and bring the bottle of frozen water to school the next day. (The milk bottle will look as if it were wearing an ice cap. Just before water freezes and changes into ice, it expands.)

Ask the children to do this experiment at home. Fill an ice cube tray with water until the water overflows. Freeze into ice cubes. Find out whether the ice cubes *will fill, partly fill, or more than fill the tray.* (They will more than fill the tray.)

Fill a screw cap jar with water and tightly screw on the cover. *Predict* what will happen if this jar of water is changed into ice. (The jar will break.) Place the jar inside a paper bag for safety in handling. Freeze the jar full of water to check the predictions.

Weigh a dry piece of porous rock, such as sandstone, Place the sandstone in a jar of water and observe the air bubbles that escape from the surface of the rock. Discuss the source of these air bubbles and why they escape from the pores in the rock. (The water is replacing the air in the rock's pores.) Remove the rock from the water, wipe it with a towel, and weigh it again. (The wet sandstone should weigh more than it did when it was dry.) Some children may want to prove by experiment that a given amount of water weighs more than an equal amount of air. Let these children plan experiments to be done for the class.

Discuss how ground water seeps into the pores and cracks in rocks and *what may happen* to the rocks if this water freezes. Experiment with porous and cracked rocks. Soak the rocks in water and place them in pans in a freezer. When the rocks are removed from the freezer, look for changes in the rocks. Allow the rocks to return to room temperature and observe them again for any change. This experiment may need to be repeated several times. Soak the rocks each time before freezing. Observe whether the repeated freezing and melting of the water caused any observable changes in the rocks. Some of these changes may have occurred: the cracks may be wider, deeper, or longer; the rocks may break into two or more pieces; or small sediments may break from them.

If slate shingles are used on the roofs of houses in your community, interview the home owners with a questionnaire similar to the following one.

QUESTIONS	ANSWERS
1. Have some of the slate shingles on your roof broken?	________
2. Have you any reason to think that changes in temperature may have caused them to break?	________
3. During what months did the most breakage occur? Why?	________
4. What other conditions may have caused some of the breakage?	________

If *exposed bedrock* is found near your school, take a trip to examine the shapes of the rock fragments that have broken from it. The expansion and contraction of the bedrock, produced by changes in temperature and the melting and freezing of water, may have caused these fragments to break from the bedrock. (Some kinds of rocks, such as *granite, syenite,* and a dark-colored rock called *basalt,* peel off, or exfoliate, after long exposure to weathering. This process is called *exfoliation* because the rock fragments resemble rough, jagged, thin leaves, or foliage.) *Shales, limestones,* and *sandstones* break off in rough, jagged layers. See pictures of these rocks (Figs. 6.8 and 6.10). Different kinds of rocks have characteristic ways of weathering.

Discuss road signs that read: "Watch for Falling Rocks" or "Danger! Falling Rock Zone." Weathering causes not only small rock fragments but also huge blocks of rock to break loose from the bedrock. In winter, water expanding and freezing in the cracks of rocks may enlarge, deepen, or widen these cracks, or it may pry loose small and large pieces of bedrock. As long as the ice remains frozen, it holds the pieces together. When the ice thaws in the spring, these broken fragments come tumbling down the mountain; if highways are built very close to the sides of mountains, some of these rocks are likely to fall onto the road. These highway signs are danger signals, warning drivers to proceed with caution.

Ask each child in your class to examine the paved sidewalk between his house and the school. Look for breaks and upheavals in these synthetic rocks. Where breaks and upheavals occur, look for evidence of the force that caused the breaks. (The growing trunks and roots of trees cause some of these breaks and upheavals.)

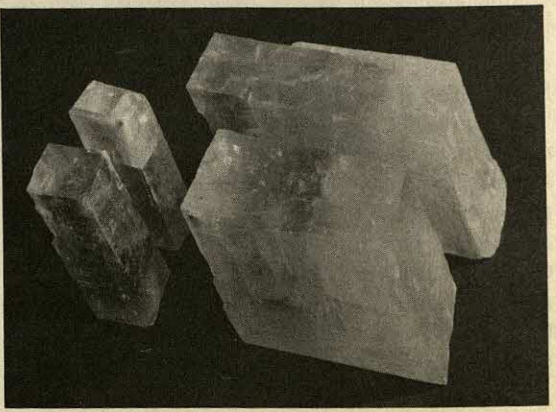
Find a place where tree seedlings and other plants can be observed growing in the cracks of exposed bedrock. Discuss the force that these growing plants exert, and the way that this force can cause the rocks to break.

Fill a coffee can with dry beans and water. Put the cover on the coffee can and set it in a warm place. Each day, add some water. (The beans will begin to sprout and grow.) Observe whether the growing beans exert any *force* on the cover of the coffee can. (The beans will lift the cover.) Have the class plan and do their own variations of this experiment—use a glass jar with a tight lid. Also, try to grow bean seeds in cracks in rocks.

5. Why do rocks have different colors and textures?

Select rocks of different colors and textures, break them, and compare the inner and outer surfaces for color and texture. Use magnifying glasses to examine the rocks. Explain why the inner and outer surfaces of rocks do not always look and feel the same. Summarize some of the factors that cause changes in the outer surface of

Fig. 6.2 Feldspar. *Ward's Natural Science Establishment, Inc.*



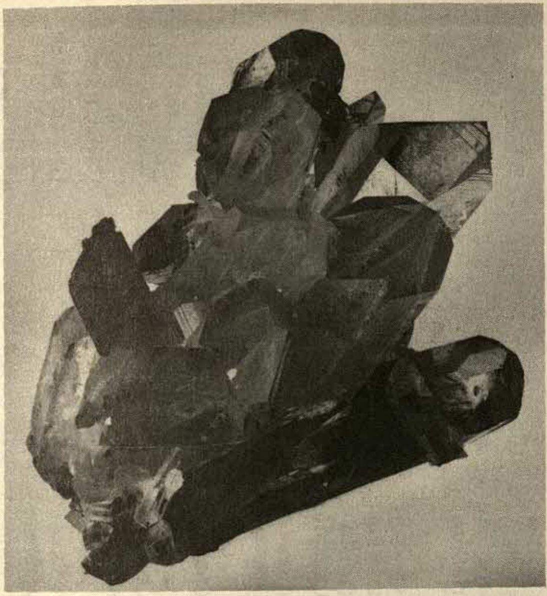
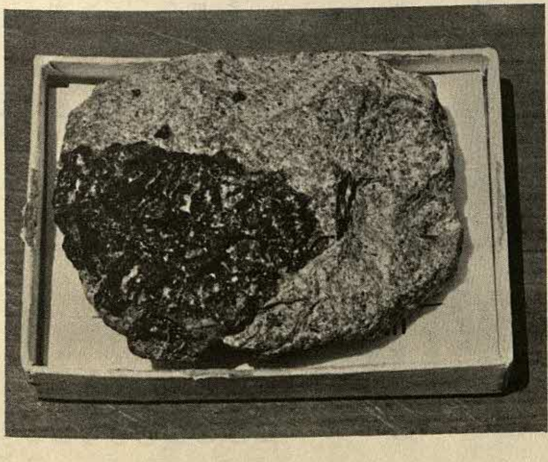


Fig. 6.3 Quartz. *Ward's Natural Science Establishment, Inc.*

rocks. (Among these factors are sun, temperature, water, ice, snow, air, wind, and plants.)

Examine again the inner surfaces of the children's rock fragments and try to determine the number of colors they contain. Some may show more than one color; others *seem* to be made of only one color. Help the class to understand that *rocks are made of minerals* and that minerals are of many colors. The children should also realize that some minerals in rocks may be present in such small grains that they cannot be detected with magnifying glasses: thus, such rocks as sandstone, shale, limestone, quartzite, slate, and marble appear to be composed of just one kind of mineral.

Fig. 6.4 Hornblende (dark mineral).



Borrow from the science supply room the collection of common minerals and observe their colors and textures. From the collection choose the four common minerals[1]—feldspar, quartz, mica, and hornblende—learn to recognize them and to know their names. See photographs of these minerals in Figs. 6.2, 6.3, 6.4, and 6.5.

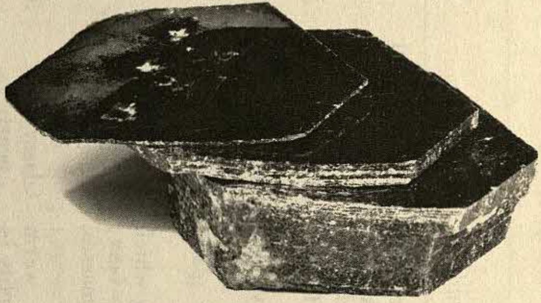


Fig. 6.5 Mica. *Ward's Natural Science Establishment, Inc.*

Feldspar	White, pink
Quartz	Glassy, colorless to rose to smoky crystals with many other color variations
Mica	Thin, colorless to black, transparent sheet or flakes which bend
Hornblende	Dark-colored

Look for small quantities of these four common minerals in rock fragments. These minerals can be seen in:

Gray granite	(1) Feldspar, white; (2) quartz; (3) mica or hornblende
Pink granite	(1) Feldspar, pink; (2) quartz; (3) mica or hornblende
Syenite	(1) Feldspar; (2) little or no quartz; (3) mica or hornblende

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[1] See identification key in Table 6.1 for information about other minerals.

Table 6.1

IDENTIFICATION KEY TO SOME OF THE COMMON MINERALS

Name and Composition	Color	Distinguishing Characteristics	Luster	Hardness	Streak	Specific Gravity
Calcite $CaCO_3$	Colorless, white, and variously tinted	Effervesces in cold dilute hydrochloric acid (HCl); objects viewed through clear crystals (Iceland spar) appear double; stalactites and stalagmites in limestone caves are noncrystalline calcite	Glassy to dull	3	White	2.7
Chalcopyrite $CuFeS_2$	Brassy yellow	Softer than pyrite and more golden yellow; often tarnishes iridescent	Metallic	3.5–4.0	Greenish-black	4.2
Chert or Flint SiO_2	White to gray to black	Tends to splinter and fracture like glass; irregular massive	Dull	7	White	2.6
Chlorite FeMgAl-silicate	Green of various shades	Can be bent like mica; unlike mica which is elastic and snaps back, it stays bent; occurs in sheets, scaly flakes or masses, and cubelike crystals	Glassy to pearly	2–2.5	White to pale green	2.6–3.0
Dolomite $CaMg(CO_3)_2$	Colorless, white, and variously tinted	Powdered mineral effervesces in warm dilute hydrochloric acid (HCl); splits in cubes; occurs in crystals or fine-to-coarse-grained mass	Glassy to pearly	3.5–4.0	White	2.8
Feldspar orthoclase K and NaAl-silicates	Colorless, white, yellow, cream, flesh, red, and green	Two of its sides split at right angles (90°); may show network of tiny threadlike markings but no parallel striations; orthoclase ($KAlSi_3O_8$)	Glassy to pearly	6	White	2.6
Feldspar plagioclase Na and CaAl-silicates	White, gray, rarely other colors	Two of its sides split at angles of 86°; smooth faces may show parallel striations and often show play of colors; Albite feldspar ($NaAlSi_3O_8$); Anorthite ($CaAlSi_3O_8$)	Glassy	6	White	2.6–2.8
Fluorite CaF_2	Colorless, black, white, violet, green, yellow, pink	Commonly found in cubic crystals; splits in eight-sided crystalline masses	Glassy	4	White	3.2
Galena PbS	Blue, black or lead-gray	Very dense; splits in cubic granular masses; exists in cubic crystals	Metallic	2.5–2.7	Gray, black	7.4–7.6
Garnet CaMgFe or Al-silicate	Colorless, white, yellow, red, brown, green, black	Fractures unevenly; occurs in twelve, twenty-four, and unequal four-sided crystals	Glassy	7–7.5	White	3.5–4.3
Graphite C	Steel-gray to iron-black	Feels greasy; soils finger; occurs in flakes, scales, or veins; flexible but stays bent; not elastic like mica	Metallic	1	Gray to black	2.3

Gypsum $CaSO_4 \cdot 2H_2O$	Colorless, white	Fingernail scratches it; occurs in granular and fibrous masses and in flexible but not elastic sheets; coarse, granular mass used to make plaster of Paris; fine granular mass is called *alabaster;* fibrous variety called *satin spar*	Glassy, pearly on smooth faces	2	White, gray	2.3
Halite (salt) NaCl	Colorless, white, red, blue	Tastes salty; occurs in cubic crystals and granular masses; splits into perfect cubes; dissolves in water	Glassy	2.5	Colorless, white	2.1–2.6
Hematite Fe_2O_3	Red-brown, steel-gray, black	Usually occurs in noncrystalline, fibrous, oölitic (shaped like fish eggs), or compact earthy masses	Metallic, dull, or earthy	5.2–6.5	Cherry-red to dark-red	4.9–5.3
Hornblende $(Ca\ Mg\ Fe)_3$-silicate Ca Mg Al_2-silicate	Black, dark green or dark brown	Occurs in slender, six-sided crystals, in grains and masses	Glassy	5.5		3.2
Ice H_2O	Colorless to white	Ice, snow, frost, water, water vapor, steam; dissolves many other minerals and transports them to new locations; forms crystals	Transparent to translucent	2		0.92
Limonite Hydrous Iron Oxide	Yellow-brown to black	Earthy form will mark paper; iron rust	Glassy to dull, metallic to earthy	5–5.5	Yellow-brown	2.7–4.3
Magnetite Fe_3O_4	Black	Magnetic; very dense; lodestone is magnetite	Dull, metallic	6	Black	5.8
Mica (biotite) KMgFeAl-silicate	Dark brown or black	Occurs in flexible and elastic sheets; splits in thin, smoky-colored, horizontal sheets; known as *black mica*	Glassy	2.5–3	White to brown	2.8–3.4
(muscovite) KAl-silicate	Colorless, silvery-white to pale green or brown	Occurs in flexible and elastic sheets; splits in thin, colorless, horizontal sheets; known as *white mica*	Glassy, pearly	2–2.5	White to brown	2.8–3.0
Pyrite FeS_2	Brassy yellow	Called *fool's gold* because it is often mistaken for gold	Metallic	6–6.5	Greenish-black	5.1
Quartz SiO_2	Colorless, white, smoky rose, gray	Six-sided crystals; fractures like glass	Glassy to greasy	7	White	2.6
Talc Hydrous Mg-silicates	White, apple-green, gray	Feels greasy or soapy; occurs in scales, fibrous and compact masses; in compact mass, it is called *soapstone*	Pearly, greasy	1	White	2.7

6. How are minerals identified?

Plan a field trip to collect rocks and minerals. Before taking this trip, discuss some of the rules that a good rock and mineral collector follows. A good rock and mineral collector never collects more rocks and minerals than he needs. He takes a bag containing the proper tools for use in the field. He needs a well made hammer, cold chisel, temporary labels, newspaper, pencil, and notebook. As he collects each mineral sample, he writes on the label the name of the mineral (if he knows it) and the place where he found it. Then he places the label together with the rock or mineral on a piece of newspaper and carefully wraps the sample to keep it from being damaged by other samples in the bag. When he returns from the field, he does the necessary reading and testing to identify the samples. As each rock or mineral is identified, he permanently labels and places it in a suitable box or case. (Cardboard egg cartons make good storage boxes for children's collections.)

After returning from a field trip, try to identify the rocks and minerals that were collected. Field guides to rocks and minerals and the school's collections can be used to help identify rocks. Masking tape, on which the children write the probable name followed by a question mark, makes good temporary labels. Use the temporary labels until a number of rock and mineral guides have been consulted, the tests for identifying minerals suggested in this problem have been done, and local geologists have checked the rocks and minerals.

Rocks are identified by the minerals they contain. Learning to recognize some of the common minerals (see Table 6.1) can help the children identify the rocks in their own collection. For each mineral in their rock collections, find such information as:

1. Its *chemical composition.*
2. Its *luster.*
3. The typical *color* in which the mineral occurs or the color of the *streak* (mark) it makes on the unglazed back of a tile.
4. Its *hardness.*
5. Its *specfic gravity.*
6. Where it can be *found.*
7. How it is *used.*
8. Interesting *facts* about it.

The chemical composition of a mineral is described in its formula. A mineral is either an element or a compound with a definite chemical composition. If the children have previously solved the problems in Chap. 11, they should know some of the chemical symbols for the different elements. (See Table 11.2.) They should also know that chemists use formulas to show the chemical compositions of the molecules in each kind of compound. If they have not had these experiences, select and develop experiences that will help them understand the chemical composition of minerals.

Help to develop understandings of such words as *glassy, dull, metallic, pearly, earthy, greasy,* and so on, which are used to describe the luster of a mineral. Help the class use these terms to describe the minerals in the school collection.

The characteristic *streak of a mineral* is a more reliable *color clue* to its identity than visible color. Find the identifying streak or mark left by a mineral by dragging the mineral across a piece of unglazed tile. (Bathroom tile has one unglazed surface.) The characteristic color of the streak left by some of the more common minerals is listed in Table 6.1.

A mineral's hardness is another identifying characteristic. Commercial kits are available containing minerals with a hardness range of 1–10. If your school does not own such a kit, collect substitutes for testing the hardness of the minerals the children want to identify. (See Table 6.2 for the minerals contained in a mineral hardness kit and substitutes that can be assembled.)

Find the hardness of a mineral by using the following method. Since many common minerals have a hardness of 7 or less, it saves time to scratch the minerals to be identified with quartz (hardness 7) or a steel file (hardness 6.5). If the quartz or the steel file scratches the mineral, its hardness is less than 7 or 6.5. Be sure that a distinct scratch has appeared on the unidentified mineral before continuing with the test. Rub your fingers over the scratches. If the marks disappear, they are not real scratches. If the unidentified mineral scratches the quartz or the steel file, its hardness is greater than 6.5 or 7. If the unidentified mineral scratches the window glass and is scratched by the steel file, its hardness is between 5.5 and 6.5. If the unidentified mineral scratches talc, gypsum, and calcite and is scratched by fluorite, its hardness is between 3

Table 6.2

A COMMERCIAL KIT AND SUBSTITUTES FOR TESTING THE HARDNESS OF MINERALS

Minerals in Commercial Kit	Hardness	Substitutes	Hardness
Talc	1	Fingernail	1–2.5
Gypsum	2	—	—
Calcite	3	Penny	3
Fluorite	4	—	—
Apatite	5	Knife blade or window glass	5.5
Feldspar	6	Steel file	6.5
Quartz	7	—	—
Topaz	8	—	—
Corundum	9	—	—
Diamond	10	—	—

and 4. If the unidentified mineral is scratched by the fingernail, its hardness is between 1 and 2.5. (Caution the children not to test minerals from display collections or valuable crystals.)

Encourage a few children to look up the method used to determine a mineral's specific gravity. The specific gravity of a mineral is a number which compares the relative weight of the mineral to the weight of an equal volume of water. Calcite, for example, with a specific gravity of 2.7 is 2.7 times as heavy as an equal volume of water. The method for determining the specific gravity of pure minerals is given in most books on rocks and minerals. It involves weighing the mineral in air and in water and doing some arithmetic. Give these students some samples of pure quartz, mica, and so on, and let them show the class how mineralogists determine that quartz has a specific gravity of 2.6 and mica a specific gravity of 2.8 to 3.0.

Select samples of different minerals and place them in a pan. From the school science supply room, obtain a small bottle of *dilute* hydrochloric acid, a medicine dropper, and a beaker. Pour a little of the acid into the breaker. Use the acid from the beaker in these tests: Put one or two drops of this acid on each mineral. Observe what happens. (Some minerals will effervesce or bubble.) Use tongs to separate those minerals which effervesce from the others. When finished, wash all rocks in clear water to remove the acid. (Do not touch acid.) Use Table 6.1 to find the common minerals that effervesce in hydrochloric acid. Use several other methods for identifying these minerals. (See Table 6.1.)

Encourage some of the children to report to the class about some simple crystal forms of common minerals. They can illustrate their report with crystals from the mineral collection. They can also grow some salt (halite) and borax crystals from concentrated solutions. (They can make these solutions by dissolving salt and borax in hot water until the water will dissolve no more of the mineral. To grow crytals from the concentrated solutions, hang loosely woven, heavy cotton strings down into the concentrated solutions. In a few days, the strings will be covered with crystals.) When the children report to the class, they can show these crystals under the microscope or with the microprojector. At the same time, they can scrape some frost from the freezing compartment of a refrigerator to see ice crystals.

A number of companies sell kits containing fluorescent and phosphorescent minerals together with a mineral light or an argon lamp. Some members of your class may own these kits. Fluorescent and phosphorescent minerals emit characteristic and often beautiful colors when exposed to ultraviolet light. Learn to distinguish between fluorescent and phosphorescent minerals. A mineral that emits a certain color *during* its exposure to ultraviolet light is called *fluorescent.* A mineral that *continues to glow* after the source of ultraviolet light has been removed is called *phosphorescent.* There are a number of different wave lengths in ultraviolet light; the makers sell several different kinds of lamps, which emit different series of long or short wave lengths. A child's kit, or the school's, is more likely to have either a short wave-length ultraviolet light called a *mineral light* or a long wave-length ultraviolet light called an *argon lamp.*

Table 6.3 lists the minerals that emit colors upon exposure to either of these sources of ultraviolet light. Notice that the table also lists the location of these minerals. This information is given because not all varieties of these minerals are fluorescent or phosphorescent. Notice, too, that fluorescent minerals are more common than phopshorescent ones.

Mineralogists use other tests in addition to those described to help them identify minerals. They have ways to determine the chemical composition of a mineral and to find its characteristic

Table 6.3

LIST OF FLUORESCENT AND PHOSPHORESCENT MINERALS

Name of Mineral	Argon Lamp (long wave-length ultraviolet light)	Mineral Light (short wave-length ultraviolet light)
Autunite	Bright yellowish-green	Bright yellowish-green
Calcite X line, Texas I	None	Pale cream
Calcite X line, Texas II	None	Strong bright blue
Calcite, Franklin, N.J.	None	Brilliant rose-red and blue *phosphorescent*
Calcite and willamite, Franklin, N.J.	Bright green	Bright rose-red and green *phosphorescent*
Fluorite, England	Bright blue	Dull blue
Fluorite, Ohio	Yellowish-green	Yellowish-green
Opal massive, Nevada	Green	Green
Petroleum in bottle	Bright green	Bright green
Scapolite, Canada	Bright golden-apricot	Dull yellow
Scapolite in quartz	None	Blue
Scheelite in quartz	None	Blue
Tremolite, New York	None	Pink
Willamite with Franklinite, Franklin, N.J.	Bright green	Bright green
Willamite with calcite, Franklin, N.J.	Green	Brilliant green and rose-red

method of breaking (fracture) and splitting (cleavage). They also use certain flame tests to help them identify a mineral.

Divide the class into four committees. Assign one mineral—feldspar, hornblende, mica, and quartz—to each (see Figs. 6.2, 6.3, 6.4, and 6.5). Ask the committees to find information about their respective minerals and to report their findings to the class.

As each committee reports, have it make for the bulletin board a chart containing information like that found in Table 6.1.

7. What are rocks? How are rocks classified?

These two inquiries are best solved by consulting such reference books as encyclopedias and rock and mineral guides for locating information. As the information is discussed, organize it under the two problems being solved. These are some of the facts that may be presented:

What are rocks?

They make up the earth's crust.

They are composed of one or more minerals.

Most rocks are solid.

Sand, mud, and volcanic ash, also, are called *rocks.*

Coal, formed from plants that were once alive, is called a *rock.*

What are the classes of rocks?

There are three classes of rocks: igneous, sedimentary, and metamorphic. The names "igneous," "sedimentary," and "metamorphic" describe how the rock is formed.

Igneous rocks are formed from molten mixtures of minerals. When mixtures of minerals are in a molten (liquid) state, they are called *magmas.*

Sedimentary rocks are composed of sediments or fragments of rocks. These sediments and fragments usually have been carried from one place to another where they are slowly changed into solid rock. Running water, ice, gravity, and even living things transport these materials to the places where they are changed into sedimentary rocks. Fossils are commonly found in sedimentary rocks.

Metamorphic rocks have been changed by heat, pressure, or solutions of other minerals. Both igneous and sedimentary rocks can be changed into metamorphic rocks. Metamorphic rocks can be further metamorphosed, i.e., changed.

8. Which rocks are igneous? How can igneous rocks be identified?

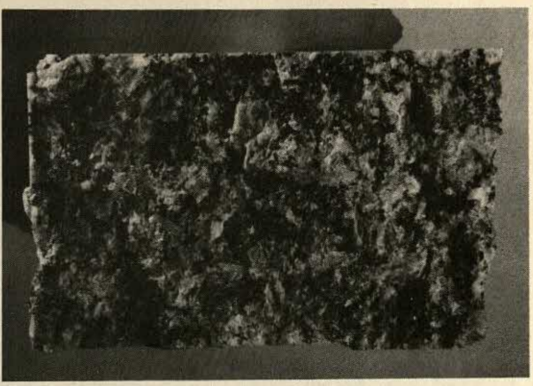
Use reference books to find the names of some of the more common igneous rocks (see Table 6.4 and Figs. 6.3, and 6.6a, b, c).

Borrow the school collection of igneous rocks and examine it. Note the different kinds of rocks.

Ask the children to examine their personal collections to see whether they have any igneous rocks similar to those in the school collection. Invite some local geologist or mineralogist to discuss the igneous rocks common to your area and to help the children check the identification of the rocks in their collection and give them some further clues. The authority may give them clues like these: Igneous rocks are *not in layers.* Their texture or surface is characterized by masses of *large crystals, small crystals,* or a *glassy noncrystalline* appearance (see first column of Table 6.4). If the rock has either size of crystals or is glassy, decide whether it is predominantly *light-colored, dark-colored,* or *very dark-colored.* If the rock has large crystals and is light-colored, it may be granite or syenite. If it has large crystals and is dark-colored, it may be either quartz diorite or diorite. Similarly if the rock has small crystals and is light-colored, it may be either rhyolite or trachyte. Finally, to distinguish between granite or syenite, quartz diorite or diorite, rhyolite or trachyte, etc., have the children determine whether or not quartz is present by using the hardness test. (See pages 72 and 73.) If quartz is present in the rock, it will scratch a steel file, because quartz has a hardness of 7. One of each pair contains quartz; the other does not.

Look at samples of granite, syenite, quartz diorite, and diorite, and read about them. These four are common igneous rocks and contain all or some of the four readily distinguishable minerals: feldspar, hornblende, mica, and quartz.

A *syenite* rock contains a light-colored (white or pink) variety of feldspar called *orthoclase* and one or more of the following minerals: mica, hornblende, augite. *Granite* differs from syenite in that it contains quartz. *Quartz diorite*



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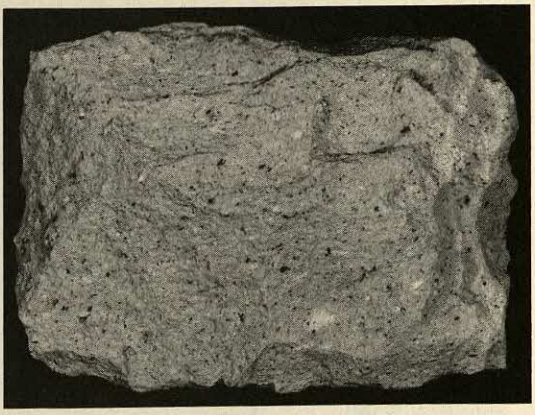

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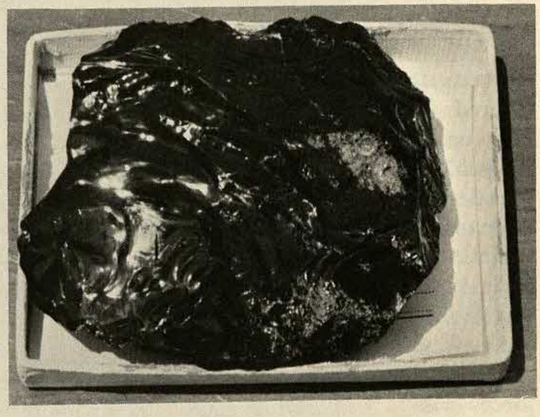


(c)

Fig. 6.6 (a) Granite—large crystals. *Ward's Natural Science Establishment, Inc.* (b) Rhyolite—small crystals. *Ward's Natural Science Establishment, Inc.* (c) Obsidian—no crystals.

Table 6.4
IGNEOUS ROCKS

Color

Composition and Texture	Light (orthoclase feldspar: white, pink)		Dark (plagioclase feldspar: gray)		Very Dark (no feldspar, only dark-colored minerals)
	Quartz	Quartz usually lacking	Quartz	No Quartz	
Large crystals 1. All visible	Granite	Syenite	Quartz diorite	Diorite; gabbro	Periodite; Pyroxenite
2. Crystals of one mineral visible; others invisible (add the term *porphyry*)	Granite porphyry	Syenite porphyry	Quartz diorite porphyry	Diorite porphyry; gabbro porphyry	
3. Very large crystals (add the term *pegmatite*)	Granite pegmatite			Diorite pegmatite	
Small crystals 1. Invisible	Rhyolite	Trachyte	Dacite	Andesite basalt	Occur only rarely
2. Crystals of one mineral visible; others invisible (add the term *porphyry*)	Rhyolite porphyry	Trachyte porphyry	Dacite porphyry	Andesite porphyry; basalt porphyry	
No crystals 1. Glassy 2. Fragmental	Pumice, obsidian, pitchstone, perlite, volcanic ash or tuff, breccia				

contains the mineral quartz, one of the dark-colored varieties of feldspar called *plagioclase*, and one of the other dark-colored minerals found in syenites and granites. *Diorites* are darker than granites and syenites, because they contain larger amounts of the dark-colored minerals. Other varieties of diorites lack quartz, but contain the same kinds of minerals that are present in the quartz diorites.

Crush samples of granite, syenite, quartz diorite, and diorite into small pieces. Examine the pieces with a magnifying glass. Try to identify the different kinds of colored minerals present in these samples. Note whether the sizes of the different crystals are approximately the same. (They should be.) How many of these rock samples contain large amounts of quartz? (Granite and quartz diorite) How many of these rocks contain feldspar? (All of them) Why do you think these rocks are given different names? (Check your answer with textbooks on rocks and minerals.)

If possible, show the children granite, granite porphyry, granite pegmatite, rhyolite, and rhyolite porphyry. Be sure they understand that each contains the *same minerals*, but that the *texture* of each is different. Granite *pegmatite* contains the minerals in larger masses than granite. The name *porphyry* added to granite indicates that one kind of large visible mineral crystal is embedded in a mass of microscopic crystals of the other minerals. *Rhyolite* contains the same kind of minerals as granite, but the mineral grains are all so small that they cannot be detected without a microscope. In rhyolite *porphyry*, one kind of mineral can be seen in a mass of microscopic crystals of the other minerals.

9. How are igneous rocks formed and distributed?

Ask the children to solve this problem by consulting authorities. Their research should produce some of these facts:

> Igneous rocks are formed from molten mixtures of minerals which in the molten state are called *magmas*.
>
> Geologists believe that, at depths of ten miles or less, pressure, caused by the weight of overlying rocks in the earth's crust, and heat, released by the radioactive minerals which are present in some rocks, produce enough heat to liquefy rocks.
>
> As long as the pressure on the rocks at these depths is equal in all directions, even though the rocks are hot enough to change into a liquid, they cannot expand into a liquid state and they cannot flow. But, if the pressure becomes unequal, these very hot rocks will have room to expand; they then move away from the area of greater pressure and continue moving until the pressure is again equalized.
>
> Throughout the earth's history, magmas formed within the earth's crust have moved upward and outward into other rock formations or have flowed out over the surface rock itself.
>
> The igneous rocks, which are formed from the magmas which flow out over the surface rock, are classified as *extrusive*. If the magmas form igneous rock within the earth's crust, they are classified as *intrusive*.
>
> Geologists believe that, when the earth was very young, there was only one class of rocks —igneous. According to generally acceptable theories, the solar system, of which the planet Earth is a member, evolved from gases and dust which changed into igneous rock.
>
> As far as geologists know, none of the original mantle rock that covered the earth's surface exists today. This original igneous rock has been either changed into metamorphic rocks or weathered and eroded away. Igneous rocks that are exposed on the earth's surface today are believed to be much younger than the original igneous rock which covered the earth several billion years ago.

Ask the children whether they can think of any forces at work on the earth today that may cause the pressure of surface rocks to be greater in one region than in another. Guide their thinking with questions like these: (1) What forces are at work changing the earth's surface? (Weathering and erosion) (2) What happens to weathered rock and soil that is washed into a stream? (Much of it is carried downstream to a larger stream, to a lake, or to the ocean.) Geologists believe these millions of tons of rock debris and organic materials that are continuously being carried away from the land and deposited in the ocean eventually build up enough pressure to cause rocks deep under the ocean's floor to flow away from the ocean and toward the land masses and slowly to raise the land farther above sea level. This is a very simple explanation of the *theory of isostasy*. Isostasy explains why a vertical section of rock removed from the ocean floor has a weight equal to a comparable vertical section or rock removed from the continental land mass. It also helps us understand why, although the land is constantly being worn away, there will always be land masses above sea level.

Have one of the children blow up a balloon just large enough to fit into the palms of his hands when he cups them together. Tie off the neck of the balloon to prevent the air from escaping. Have the child cover the balloon with his hands and squeeze it together, applying *equal pressure* in all directions. What happens to the balloon? (It becomes smaller.) Release the pressure and the balloon expands to its original size.

Have another child hold the balloon firmly in the palm of one hand. Ask him to press his thumb inward on the balloon. Call the attention of the class to the depression the thumb makes in the balloon and to the ridge all around his thumb. Be sure that the children watching this experiment realize that the child's thumb represents the weight of all the rock debris and organic material dumped into the ocean. The depression represents the ocean; the ridge, the mountains or land masses that rise around the oceans.

Look at a world map showing the major

mountain ranges. Observe whether the major mountain ranges are in the middle of the large continental masses or near the coastline. (Most major mountain ranges are very near coastlines.)

Ask the children whether they think the earth's rocky crust is made of *one great mantle* of rock or of *many huge irregular-sized blocks* of rock. (Geologists believe it is made of large irregular blocks.) Tell them to observe some of the cliffs, exposures of bedrock, or large rock surfaces in their area. They can also study pictures of areas of the world where the earth's crust is exposed. (A large piece of rock without cracks is rare. It costs much more to buy such a piece than to buy a number of smaller pieces that, together, equal it in size.)

Help the children visualize the block formation of the earth's crust by having them stack different-sized wooden blocks in a pan. With this model before them, ask them what they think would happen if these blocks were stacked in a pan partially filled with mud. (The mud would rise up into the spaces between the blocks and between the blocks and the pan.) Ask them what they think would happen if the magma on which the rocks of the earth's crust rest began to flow. (The magmas would push into the spaces between the rocks and pry them father apart.) Sometimes these magmas will reach the surface through one of these cracks in the earth's crust and flow out over the surface. Magmas that erupt through surface rocks are called *lavas.* When these magmas cool, they form *extrusive* igneous rocks, such as obsidian, tuff, breccia, and basalt. Many times, however, the magmas do not reach the surface but flow outward in a horizontal direction through the earth's crust and uplift it. When this happens, if the magma flow is large enough, the surface rocks may be uplifted several thousand or more feet. Smaller magma flows may cause only a slight rise in the surface rocks.

Magmas that intrude between surface rocks form *intrusive* igneous rocks. Granites, syenites, and diorites are instrusive igneous rocks. In Inquiry 8, the class learned about the mineral composition and granular texture of these rocks. The larger grained rocks were formed at greater depths in the earth's crust; the finer grained rocks were formed nearer the surface.

Ask the class to read about lava flows. They should report on lava that flows over the surface of the earth in *sheets*, as a river overflows its banks, on lava that builds volcanoes by successive eruptions over a period of many years, and on lava that is violently and explosively extruded by suddenly breaking through the earth's surface or by the pressure caused by expanding steam and other gases in the lava.

Discuss with the class where they might look for igneous rocks and why they might expect to find them there. The children should be able to suggest these places:

PLACES	REASON
1. Northern gravel deposits	Glaciers transported and deposited all kinds of rock fragments, including igneous rocks.
2. Stone quarries	Much igneous rock is quarried for commercial purposes.
3. Streams, rivers, lakes, oceans	Running water transports rocks, including igneous ones, long distances.
4. Mountains	Mountains are uplifted by the pressure of magma.
5. Glaciated landscape	Melting glaciers left erratic boulders (rocks which do not match the bedrock) scattered in regions over which they passed.
6. Gravel roads	The gravel used in building these roads may have come from a gravel pit which included igneous rock.
7. Road cuts	The road cut may have been made through igneous rock.
8. Volcanoes	They are made of igneous rock.

If your area has such places, take a field trip to look for igneous rocks (see Fig. 6.9).

Have some of your children find out whether there is any relationship between the movements of magmas in the earth's crust and earthquakes. (Major earthquakes are caused by the prying, tilting, folding, and slipping of rocks in the earth's crust.) Slight local regional quakes may be caused by blasting, snowslides, and landslides. Some pupils might like to read about the seismograph, which is used to detect the waves or vibrations set up when earthquakes occur and report on their research.

10. Which rocks are sedimentary? How can they be identified?

Use reference books to find the names of some of the more common sedimentary rocks. (See Table 6.5 and Figs. 6.7, 6.8, 6.9, and 6.10.)

Examine the school collection of sedimentary rocks. Observe whether these rocks show layering or stratification. (There are usually layers in even small samples of limestone and shale.) Look at the rocks and try to identify the different sizes and kinds of sediments from which they were formed. Make a collection of pebbles (angular and round), sand, silt (granulated sugar may be substituted), and powdered clay in order to become familiar with the sizes and kinds of sediments from which sedimentary rocks are formed. If the pupils have samples of sedimentary rocks in their personal collections, have them pound one or two small pieces of each into sedi-

Table 6.5
SEDIMENTARY ROCKS

Predominantly Formed from	Size and Kind of Sediments	Physical Features	Name of Rock
Rock fragments	1. Pebbles (about 1/16″ or larger)	(a) Angular edges on pebbles embedded in a homogeneous ground mass (matrix)	Breccia
		(b) Round and smooth pebbles embedded in a sandy ground mass (matrix)	Conglomerate (puddingstone)
	2. Sand (about 1/16″ or smaller)	(a) Visible sand grains in massive or stratified matrix	Sandstone
		(b) Sandstone containing noticeable feldspar	Arkose
	3. Silt (about size of grains of granulated sugar)	Very fine visible grains; feels gritty	Siltstone
	4. Clay (about size of grains of talcum powder)	Usually stratified and soft enough to be scratched with the fingernail	Shale
Rock fragments and precipitated chemicals	Invisible and dense	Contains calcium carbonate; effervesces freely with dilute hydrochloric acid (HCl); usually massive; gray to black	Limestone
	Invisible and dense	(a) Contains calcium magnesium carbonate; the powdered rock will effervesce with dilute hydrochloric acid (HCl); massive; tan, gray to black	Dolomite
		(b) Also contains quartz; scratches glass; brittle	Chert
Precipitated chemicals	Dense to granular	Can be scratched with fingernail; white to pink	Rock gypsum (alabaster)
	Earthy	Contains calcium carbonate; effervesces freely; very soft; white	Chalk
	Porous to dense	Relatively pure calcium carbonate; effervesces freely	Travertine
	Porous	Calcium carbonate with impurities; effervesces	Calcareous tufa
	Massive	Calcium carbonate; effervesces; translucent	Cave onyx

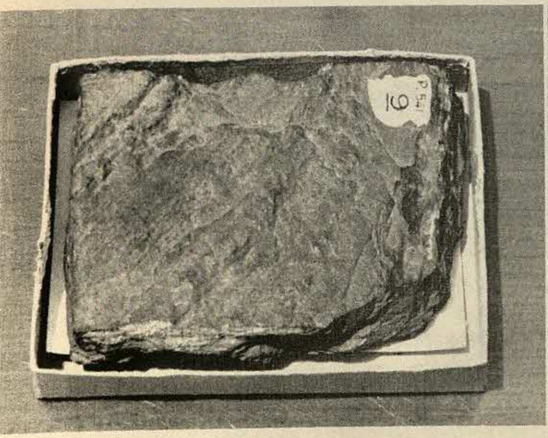
Fig. 6.7 Children examining a large conglomerate boulder. *Courtesy Eleanor Friend.*

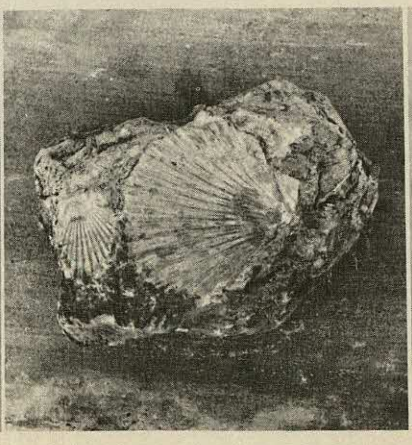
ment. Compare the size of these sediments with the sizes listed in Table 6.5 and with the size of the pebbles, sand, silt, and clay particles which they collected as examples of the sizes of sediments found in breccia, conglomerate, sandstone, siltstone, and shale.

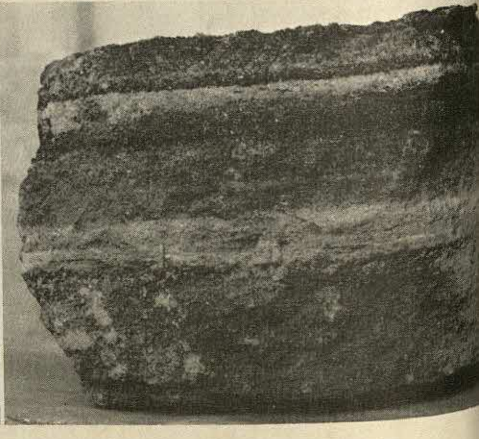
Notice in Table 6.5 that limestone, dolomite, chalk, travertine, calcareous tufa, and cave onyx all effervesce in dilute hydrochloric acid (5–10 % solution). If either calcium carbonate or calcium magnesium carbonate is present, a rock will effervesce when a few drops of this acid are placed on it. Teach the children how to remove and hold the stopper of an acid bottle in one hand so that they never need to lay the stopper on anything. Show them how to use a piece of glass tubing in the other hand to remove a small amount of acid from the bottle. (To do this, insert the tube into the acid, tightly press the index finger over the open top of the tube, lift the tube from the acid bottle, hold it over the rock. The slightest release of pressure of the index finger will cause a drop of acid to come out of the lower end of the tube and fall on the rock.) Have the children practice this skill with *a bottle containing water* until they can both control the drops and hold the stopper properly. Explain that acid must be handled very carefully in order to prevent accidents. As a part of this safety routine, as soon as they finish, have each of them rinse the glass tube, their hands, and the rocks.

To build a better understanding of the reason why sedimentary rocks are stratified, have the children do this experiment. Make a solution, following the directions given on a can of water glass (silica). Water glass can be bought at a drug store. Mix a small amount of sand, clay, or mud with the water glass solution. Place this mixture in a glass jar. Wait a day or two until

Fig. 6.8 (left) Shale.
Fig. 6.9 (center) Fossils in rock.
Fig. 6.10 (right) Sedimentary layers in sandstone.







the contents harden; then put a second mixture of water glass solution and sediments into the same jar. Place the jar in a warm place in the room. When the second mixture has hardened, the children will be able to see in the jar a "sedimentary rock" having two layers.

Some other children may want to try to make artificial breccia, conglomerate, sandstone, siltstone, and shale by using the water glass solution together with the proper size and kind of sediment.

Examine the school collection of fossils and read about the fossils in this collection. If your community has a museum, take the class to see its fossil collection. Note the kinds of fossils and the kinds of rock in which they are seen. [Your museum may have fossils of plant and animal life, rain drops, and wave action. Fossils form in sedimentary rocks (see Fig. 6.9). They are clues to the plants and animals which lived when the sediments were being laid down. They also are clues to the age of the rock.]

11. How are sediments deposited and changed into sedimentary rocks?

Discuss the forces of running water, gravity, ice, and wind, which cause sediments to move from one place to another. As any one of these diminishes, it deposits the sediments according to their weights—heavier ones first. Ask the children why they think some sedimentary rocks were formed from larger sediments than others. (The size and weight of the particles deposited is proportional to the force.) Guide the children's thinking with questions like: Where have you seen deposits of gravel, sand, mud, clay, and silt? (Gravel is usually deposited in gravel pits or near shore lines. Sand, mud, clay, and silt are usually deposited farther from the shore line than gravel.)

The following experiment shows how sediments are sorted as they are deposited in water. Mix an assortment of sediments and water in a glass jar. Observe that the gravel and sand settle to the bottom of the jar quickly. The finer sediments remain suspended much longer than the coarser ones. It may take several days or a week for the clay and silt and bits of organic matter to settle to the bottom of the jar. If water glass (silica) is added to these assorted sediments, the sediments will consolidate into layered rock. (Silica or silicates are chemicals present in ground water. These chemicals cement together the sediments in many sedimentary rocks.) Wrap the jar in a cloth, break the jar, and examine this "sedimentary rock formation."

If there is an exposure of sedimentary rocks in your region, plan a field trip to see this formation. Have the children list the materials they will need for collecting and testing rocks. Have them outline the kinds of things they may be able to observe. To guide their discussion about observations and possible tests, use the following questions: (1) What evidence shall we look for that tends to show that these rocks were formed from deposited sediments? (2) What test can we use for calcium carbonate and calcium magnesium carbonate? The children's list of things to look for on the trip might be like this:

CLUES TO SEDIMENTARY ROCKS

1. Sediments
2. Presence of calcium carbonate and calcium magnesium carbonate
3. Layers
4. Fossils

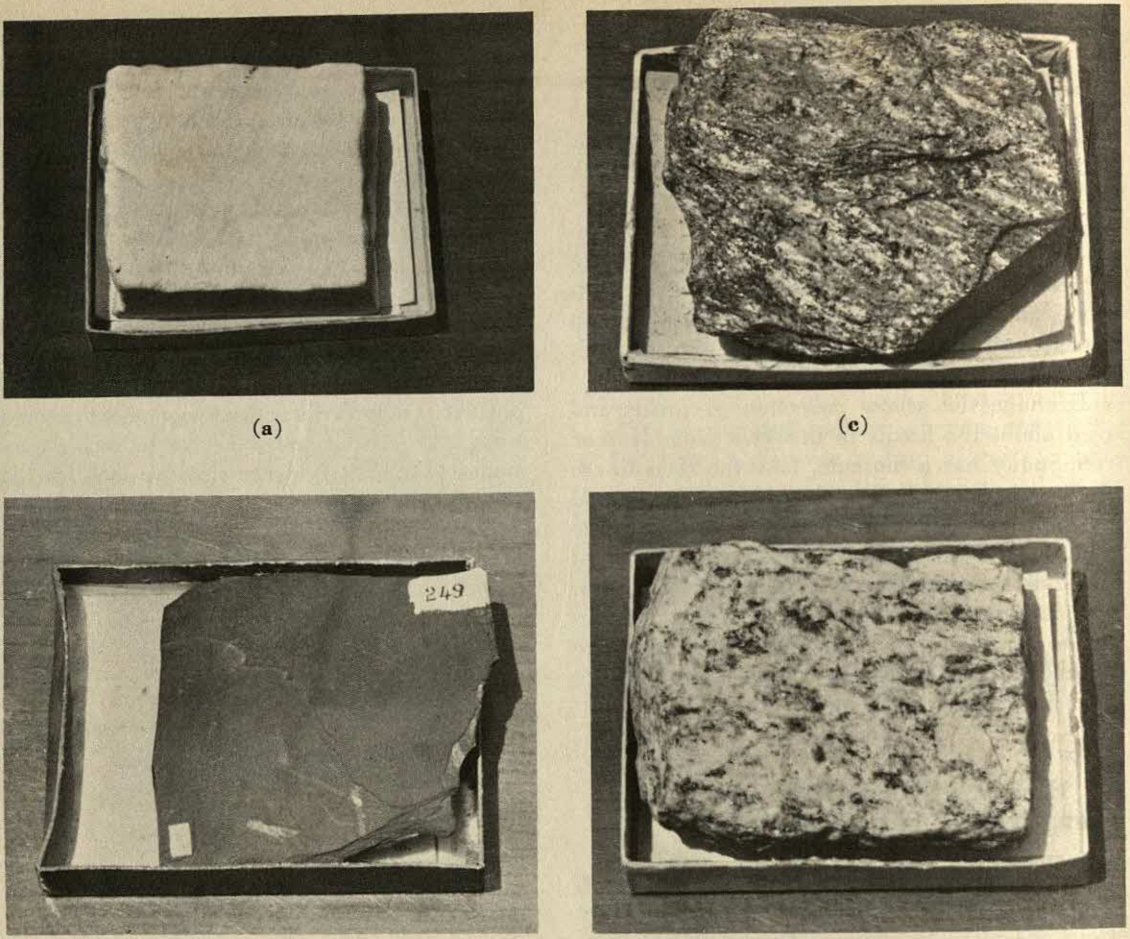
12. Which rocks are metamorphic? How can they be identified?

Both the heat and the pressure of the magmas *produce changes in the rock surrounding intrusions.* The children have learned that, when sedimentary or igneous rocks are changed, they become metamorphic rocks.

Use reference books to find the names of the more common metamorphic rocks. Also see Table 6.6 and the photographs of metamorphic rocks in Fig. 6.11a, b, c, and d.

Examine the school collection of metamorphic rocks and compare each specimen with the kind of rock from which it probably originated (see Table 6.7). Make a display like this table using samples of sedimentary, igneous, or metamorphic rock and the metamorphic form into which each may change. Ask the children to compare the weights of similar sizes of metamorphic rocks and rocks from which they originated. (Metamorphic rocks are usually more dense and heavy than the original rocks.)

Help the children build a concept of what is meant by *density*, by having them place a sponge



(a) (c)

(b) (d)

Fig. 6.11 (a) Marble; (b) slate; (c) mica schist; (d) gneiss.

Table 6.6

METAMORPHIC ROCKS

Texture	Physical Features	Name of Rock
Foliated (leaflike structure)		
Coarse-grained	Banded; bands of different minerals; contains abundant feldspar	Gneiss
	Flaky layers not distinct from each other; feldspar absent; mica, chlorite, and garnet schists typical	Schist
Fine-grained	Slaty cleavage	Slate
No grain	Coal with high luster	Anthracite
Nonfoliated		
Very coarse-grained	The texture of conglomerate, but the rock breaks across the grains as easily as it does around them. Pebbles commonly consist of chert, quartz, or jasper	Conglomerate
Coarse-grained	Chiefly calcium carbonate ($CaCO_3$); effervesces freely with dilute hydrochloric acid; color variable	Marble
Fine-grained	Dense (very heavy); dark colored	Hornfels

on the table and squeeze it into a smaller space. Also, have them cut circles the size of a coin from tissue paper, construction paper, cardboard, and aluminum foil. Suggest that they judge the weights of these cutouts and arrange them in order of decreasing weight. For additional experiments on density, see Inquiry 6, Chap. 20. Ask the class to explain what the word *dense* means. Their explanation should show that they understand the relationship between mass (amount of material) and volume (size). They may like to know that scientists define density as mass per unit volume. (Explain that *per* means *for*.) Therefore, density is the mass *for* each unit of volume.

Table 6.7

PROBABLE ORIGIN OF METAMORPHIC ROCKS

Name of Rocks	Probable Origin
Anthracite	Sedimentary: bituminous coal
Conglomerate	Sedimentary: conglomerate
Gneiss	Igneous: granite, syenite, and basalt Sedimentary: conglomerate
Hornfels	Metamorphic: slate (slate metamorphosed from shale)
Marble	Sedimentary: limestone and dolomite
Quartzite	Sedimentary: sandstone
Schist	Igneous: fine-grained rocks, such as basalt, rhyolite, and trachite Sedimentary: shale
Slate	Igneous: basalt Sedimentary: shale

Also find out whether the children know what *volume* means. If they have not formed a three-dimensional concept of volume, provide several experiences similar to this one. Measure the length, width, and height of a rectangular baking dish. Have the class compute the numbers of cubic inches of water it will hold. Fill the pan with water and weigh it. Empty the water out of the pan and fill it with sand and weigh the panful of sand. Empty the pan of sand and weigh the panful of air. The pan contains the same number of cubic inches (volume) of water, sand, and air. Which one weighs the most? (The sand.) Which one is the most dense? (The sand.)

Ask the children whether they can think of any reason why metamorphic rocks are usually more dense than the rocks from which they were formed. (They should be able to relate the experiences they had with pressure in their work on intrusive rocks to the compression that occurs when magmas force their way into other rock formations. Metamorphic rocks are usually more compact than the other two classes of rocks because they have been subjected to more pressure.)

Several varieties of metamorphic rocks can be identified by the bands and streaks of minerals in them. Gneisses, some marbles, and some quartzites are banded. Frequently, these bands are distorted into curves like hills and valleys. Maybe the children have a piece of schist that shows the folding of the entire rock into tiny hills and valleys. These streaks, bands, and distortions in rock are evidences of the pressure that has been exerted on them by mountain-building forces.

Sometimes, when magmas intrude into rock formations, they subject these formations to so much pressure that they become hot enough for the crystalline mineral masses in igneous rocks and the sediments in sedimentary rocks to change into a molten (liquid) state. During this process, the minerals can undergo several changes. The minerals may crystallize into larger masses; the minerals may flow out in streaks and bands, and the elements or minerals from the magmas may seep into the rocks. Have the children examine pieces of shale and schist and note the changes that occur when a shale is metamorphosed into a schist. (The minerals present in shales have re-formed into mica and quartz in the schist.) Let them examine pieces of limestone and marble. The mineral calcium carbonate in limestone changes into marble which is coarsely crystallized. If any other minerals are present in limestone, these minerals crystallize into the colorful patterns found in decorative marbles. These marbles are used for interior construction in buildings and for monuments. Have the children test both limestone and marble for the presence of calcium carbonate. If calcium carbonate is present, the rocks will effervesce (bubble) when a few drops of dilute (5–10%) hydrochloric acid are placed on them.

13. How are metamorphic rocks formed?

Discuss with the class their ideas of how and when rocks are metamorphosed. (They have learned that heat and pressure cause changes in the structure of rocks and should realize that both of these forces are present during mountain building.)

Different colors of crepe paper or cloth can be folded to represent the different layers of rock formations in the earth's crust. Lay the folded crepe paper or cloth on the table. Hold one end firmly against the table and slowly compress the other end by pushing it toward the end that is being held.

Cut a large balloon into a flat piece of rubber. Lay the piece of rubber on a board; fasten one end securely to the board with clamps (a narrow strip of board placed between the clamps and the rubber will prevent the rubber from tearing when it is stretched). Slowly stretch the loose end of the rubber as tightly as possible over the opposite end of the board and tack it securely. (Use a strip of board over the rubber before tacking it.) Place thin layers of different colored modeling clay on the stretched piece of rubber. Have the class observe what happens to the layers

Table 6.8

CHAPTER SUMMARY OF PROCESS SKILLS*

	Inquiries																
Process Skills for Critical Inquiry**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Observing	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				
Classifying	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				
Measuring				✓								✓					
Recognizing space time relationships			✓	✓													
Recognizing number relationships				✓	✓	✓					✓						
Communicating	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				
Inferring		✓	✓	✓	✓			✓	✓		✓	✓	✓				
Predicting		✓	✓	✓					✓			✓					
Formulating hypotheses									✓		✓		✓				
Making operational definitions	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				
Controlling and manipulating variables						✓											
Experimenting			✓	✓	✓	✓			✓	✓	✓	✓	✓				
Interpreting data																	
Formulating models									✓	✓	✓		✓				

* Fourteen essential process skills for critical thinking are listed in this table. (Read Chap. 2, "The Goals of Science Teaching.") The check marks indicate which skills can be practiced in each of the 13 inquiries in this chapter. Summary charts of process skills for four additional resource chapters can be found on the front and back endpapers of this book. Teachers could profitably construct similar charts with other chapters.

** Arthur H. Livermore, "The Process Approach of the AAAS Commission on Science Education," *Journal of Research in Science Teaching,* II (1964), 271–82.

of modeling clay when the clamps are loosened and the tension on the rubber is released. (The layers will become distorted into little mountains and valleys.) The modeling clay also can be substituted for the paper or cloth in the preceding experiment.

If there are any exposed metamorphic rocks in your area, take the class on a field trip to observe them. They may be able to see evidences of folds in these rocks or the streaks and bands that are characteristic of metamorphic rocks.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1–4. Rocks have many colors, shapes, and textures. Rocks can be broken into rough, jagged shapes, or rubbed, scrubbed, and rolled into smooth, round shapes. Moving water, falling water, moving glaciers, and wind-driven sand cause rocks to have smooth, rounded shapes. Changes in temperature, the freezing and thawing of water, the movement of glaciers, and the force of growing plants pry loose from the bedrock different-sized fragments of irregular, rough, and jagged shapes.

5–6. The different kinds of minerals in rocks cause them to have different colors and textures. Minerals can be identified by their color, streak, luster, hardness, specific gravity, reaction to hydrochloric acid, and characteristic crystal form. Mineralogists also identify minerals by their chemical composition, their reaction to ultraviolet light, and their characteristic manner of breaking (fracture) and splitting (cleavage).

7. Rocks are composed of one or more minerals and make up the earth's crust. There are three classes of rocks: igneous, sedimentary, and metamorphic.

8–9. Granite, syenite, rhyolite, and trachyte are common igneous rocks. Igneous rocks were formed from molten mixtures of minerals.

10–11. Conglomerate, sandstone, shale, and limestone are common sedimentary rocks. Sedimentary rocks are composed of sediments. Stratification, reaction to dilute hydrochloric acid, and the presence of fossils are other identifying features of sedimentary rocks. Sediments are deposited by the forces of moving water, ice, wind, and gravity. Most sedimentary rocks were formed by the consolidation of different kinds and sizes of sediments deposited by water.

12–13. Marble, slate, quartzite, gneiss, and schist are common metamorphic rocks. Metamorphic rocks are usually more dense than the rocks from which they were formed. Some have bands and streaks of minerals in them. Metamorphic rocks are formed during mountain-building activities.

Chapter Seven

The Changing Earth

INQUIRIES

1. What are some of the physical and chemical forces that cause changes in the earth's surface ?

2. What major changes have occurred in the earth's surface in the past ?

3. How old is the earth ?

4. Why is the earth's history divided into eras and periods ?

5. Which forces and changes are men attempting to control ? What attempts are men making to wisely utilize the earth's resources ?

1. What are some of the physical and chemical forces that cause changes in the earth's surface?

If the class has had the experiences in Chap. 6, have them recall some of the forces which cause physical changes in the earth's surface. As each force and the kind of change it causes is described, make a list of them similar to Table 7.1. If the class has not had the experiences in Chap. 6, do not ask them to make such a list as the one in Table 7.1. Instead use the inquiries

Table 7.1

PHYSICAL FORCES THAT CHANGE ROCKS

Force (cause)	Change (effect)
Changing Temperature Inquiry 4, p. 65	Expands and contracts surface rocks, causing them to flake or crumble
Air Inquiry 4, p. 65	Wind-driven sand erodes rock surfaces
Gravity Inquiry 4, p. 65	Causes land, rock, and snow slides; causes streams loaded with sediments to flow from higher to lower elevations
Living Things Inquiry 4, p. 65 Inquiry 10, p. 79	Plants pry rocks apart; a water solution containing acid dissolves rocks; the carbon present in plants provides the chemical necessary for the formation of coal
Water Running Inquiry 4, p. 65 Inquiry 9, p. 77 Inquiry 10, p. 79	Transports sediments from the land to the sea, thus wearing away continents; together with the sediments which it carries produces friction which causes rocks to be worn away; contains chemicals and organic materials that dissolve rock
Falling Inquiry 4, p. 65	Produces friction that causes rock formations to be eroded
Waves Inquiry 4, p. 65 Inquiry 10, p. 79	Wear back shorelines by friction; dissolve rocky shorelines by chemical action
Glaciers Inquiry 4, p. 65 Inquiry 11, p. 81	Remove, transport, and deposit sediments; form U-shaped valleys and stream beds
Mountain Building Inquiry 9, p. 77 Inquiry 13, p. 84	Tears bedrocks apart; causes rock formations to slip and slide; tilts and folds bedrocks into mountains and valleys; causes intrusions and extrusions of magma

which are listed under each force to find those experiences from the preceding chapter which pupils should have before they continue with those in this chapter. This inquiry emphasizes understandings about the changes in the earth's surface caused by chemicals present in the air and in streams, lakes, oceans, and ground water.

Ask the pupils to consider whether, in addition to the physical forces, there are other forces which can alter the rock surface of the earth. They should be aware that there are *chemical forces* as well as physical forces. Because the inquiry involves changes to *exposed surface rock,* ask the pupils to list any simple chemicals which they think can contact exposed rock. They should be able to predict that the chemicals in air and water must have weathering effects on exposed rock.

Can the effects of chemical weathering on exposed rock be observed? Encourage the pupils to collect many varieties of exposed rock, to observe the rocks carefully for evidence of weathering, and to devise experiments to help them form conclusions. They should suggest that they break the rocks in order to compare their outer and inner surfaces. If the inner rock material differs in any way from the material nearer the surface, what could have penetrated the rock to cause the change? (Air and water)

Collect and display pictures of the colorful rock formations of the western canyons. Discuss the great exposure of these rocks to air and water. Allow the pupils to speculate whether the color may result from chemical weathering. If a piece of colored canyon rock is available for breakage, check and compare the color of its inner and outer material. It is always possible for pupils in different areas of the country to make written contact and to supply each other with rock samples.

Carefully observe any stones which have pits or holes in them. Break these rocks open and find out whether the pits are on the inside as well as on the outside. If the pits are more numerous on the outside or extend all the way through the rock, the pupils should be able to guess that these pits were probably caused when minerals weathered from the rocks. Perhaps the children can identify these weathered rocks and find out which minerals weather more readily. (If the rock is granite, the feldspar and mica may have disintegrated. Quartz is much more resistant to weathering than feldspar or mica. If the rock is limestone, some of the calcium carbonate has probably dissolved and left the tiny pits in the rock.)

Note the relationship between the amount of weathering and the ease with which the rock breaks. Even such hard rocks as granites and sandstones break very readily when they are in an advanced stage of weathering.

Many weathered rocks have brown, red-brown, orange, and rust-brown stains. In some, the rust stains extend all the way through the rocks. In others, only the surface of the rock may be stained. These stains are commonly seen in weathered rocks that contain iron oxides. Iron oxides that show a rust-brown stain are called *hydrous* (water-containing) iron oxides. If the water is separated from the oxide, the color changes to gray or black. This experiment will help the children understand that the rust color in iron-bearing rocks is caused by exposure to *water and air.* Place some iron filings (a substitute for the iron-bearing rocks) on the inside of a wet glass jar. Invert the jar in a pan of water and place this setup in a warm place for at least 24 hours. When the iron has rusted, scrape off some of the rust. Place the rust on a can cover and heat it for 15 to 20 minutes. When a color change can be noticed, remove the filings from the source of heat. The heat furnished the energy necessary to separate the water from the iron oxide, and the iron filings look as they did before the rusting occurred.

Repeat this experiment with a rust-stained rock. Break the rock into two pieces; use one of the pieces for a control. Heat the second piece until a color change can be observed. Compare the color of the heated piece with the color of the control piece. Place the piece that was heated in a jar containing a small amount of water, cover the jar, and put it in a warm place in the room for a day or two. Again the rock will change its color and look the same as it did before it was heated.

The brown stains in sinks and lavatories are deposites of iron oxide and calcium carbonate that precipitated (settled) from water. These stains are frequently very difficult to remove, because the two minerals solidify into a thin cement-like coating. If there is a rust-stained sink or lavatory in your school, obtain permission for the children to try to remove the stain. Have the children wrap a piece of cloth around one end of a stick; soak the cloth in a dilute solution of hydrochloric acid (5–10%) and rub the stain with it. Leave the acid on the stain for five minutes and then wash it off with running water. Several applications of the acid may be needed to remove the stain. Some stains are so tightly cemented on the enamel or porcelain that they cannot be removed without damaging the finish.

Have the pupils summarize the preceding experiences with chemical weathering. Make sure they realize when minerals in exposed rock chemically combine with the oxygen (O_2) in the air that a kind of chemical weathering known as *oxidation* is taking place. Also they should learn that *hydration* is the chemical change in which water (H_2O) combines with minerals. See Table 7.2.

Appoint pupils to look up and report to the class information about the specific *oxides* and *hydrous oxides* in Table 7.2.

Pupils who introduce the idea that polluted water contains chemicals, will have opened an inquiry into the *possibility of chemicals in* UNPOLLUTED *water* and into the *effect* these chemicals have on exposed rock. Encourage the pupils to make educated guesses (hypotheses) regarding what chemical is probably present in lake, river, ocean, and ground water. From earlier experiences in which they tested rock with acid, they should hypothesize that *an acid may be present* in many sources of water.

Pupils who have chemistry sets may know a simple test that can be used to detect the presence of an acid. (Blue litmus paper turns red if the solution contains an acid.) Obtain some blue litmus paper and have these pupils demonstrate how it is used to test for acid. Use it to test hydrochloric acid, vinegar, water, fruit juice and solutions of salt and water, sugar and water, and

Table 7.2

CHEMICAL FORCES THAT CHANGE ROCKS

Chemical Weathering (cause)	Rock Changes (effect)
Oxidation	***Is the chemical union of*** **O_2** ***with an element or a compound.*** When minerals in the earth's outer surface are exposed to the *oxygen* in air, many of them chemically combine with oxygen to form *oxides.* These oxides ("rust") protect the fresh inner rock. Such oxides are soft.
The oxides	*Cuprite,* Cu_2O, is a copper oxide. It occurs where copper ore deposits are in arid climates and above the level of ground water. Cuprite is found in desert country where oxidation has been deep. It is often the result of the oxidation of copper sulphites. Red *hematite,* Fe_2O_3, is an iron oxide. It was used by Indians for war paint and is known as red ochre. It is the result of the oxidation of other iron-bearing minerals. *Uraninite* (pitchblende), UO_2, is a uranium oxide. Oxides are colorful. The iron oxides are red to red-brown and the uranium oxides are brilliant orange and yellow.
Hydration	***Is the chemical union of water*** **H_2O** ***with an element or a compound.*** It occurs as water seeping through soil, clay, and the cracks and pores of rock formations chemically combines with certain minerals, especially the oxides. Hydration usually follows oxidation as a secondary change. In *hydration, water* combines with *oxides* to form *hydrous oxides.*
The hydrous oxides	During *hydration, water* combines with the *iron oxide,* hematite (Fe_2O_3), to form a *hydrous iron oxide* called *limonite,* $2\ Fe_2O_3 \cdot 3\ H_2O$. Hydrous iron oxides in clays account for the yellow and brownish-yellow color of these clays. It is the coloring of soils. Powdered limonite is the ochre yellow used in paints. If limonite is moderately heated, the water is driven out and the resulting compound is hematite, the same oxide, but without the water. *Bauxite,* $Al_2O_3 \cdot 2\ H_2O$, is a hydrous oxide of aluminum. It is derived from the leaching of silica from clay minerals. Tropical weathering commonly causes this chemical change. The Picture Rocks on the shores of Lake Superior in the Upper Peninsula of Michigan derive their brilliant colors from oxides and hydrous oxides.
Carbonation	***Is the chemical union of carbonic acid*** **H_2CO_3** ***with an element or compound.*** *Carbonic acid* (H_2CO_3) is formed when carbon dioxide gas (CO_2) combines with water (H_2O). $CO_2 + H_2O = H_2CO_3$. All water, unless it is sterile, contains some carbonic acid. Raindrops falling through the atmosphere combine with the carbon dioxide in the air to form carbonic acid. Water percolating through the air-filled pores in the soil combines with the carbon dioxide there to form carbonic acid. The chief source of *carbonic acid in water,* however, comes from the chemical union of water with the carbon dioxide released from decaying and decomposing plants and animals. The carbonic acid in water attacks the surface of minerals, some of whose elements dissolve and later reappear in a solid form as *carbonates.* This chemical change, called *carbonation,* is a principle factor in the chemical weathering of rock.
The carbonates	During carbonation, the sodium, potassium, and calcium present in some feldspars are chemically changed by carbonic acid into water soluble carbonates which often are transported by water for long distances before they are ultimately deposited. The stalactites and stalagmites of limestone caves and the terraces around Mammoth Hot Springs are deposits of *calcite* ($CaCO_3$), a water soluble calcium carbonate. *Magnesite,* $MgCO_3$, is magnesium carbonate. *Siderite,* $FeCO_3$, is a carbonate of iron. *Azurite,* $Cu_3(OH)_2(CO_3)_2$, effervesces in acid and is found in association with malachite. *Malachite,* $Cu_2CO_3(OH)_2$, forms near the surface as a result of the weathering of copper sulphides and is an intense green color. If copper is exposed to the weather, it tarnishes into malachite.

chlorox and water. Vinegar, hydrochloric acid, some fruit juices etc. turn the blue litmus paper red. Probably no color change will occur to the litmus paper in water. Does this mean there is no acid in water? Does it mean that the acid may be too weak for this litmus paper test? The pupils may suggest that if a large quantity of water is reduced to a small quantity by evaporation, any acid in the water might then be concentrated enough to react to the litmus paper test. Other pupils may suggest that a solution of vinegar and water or hydrochloric acid and water could be continually diluted by the addition of more and more water until the acid in the solution becomes so dilute it will no longer react to the litmus paper test. Encourage the pupils to test both of these possibilities.

How does acid get into water? What is the name of the acid? See Table 7.2 for ways in which an acid, called *carbonic acid*, forms in water. Can the carbon dioxide in the air be made to combine with water to form carbonic acid? How can this be tested? (Pupils can pour water back and forth over and over between two jars to cause the water to contact the carbon dioxide in the air. Test with blue litmus paper until an acid reaction is obtained.)

Ask the pupils to plan tests that will enable them to discover whether larger quantities of carbon dioxide will indicate more acid is formed in water. Place a small amount of water in a clear glass container. Test the water to see if the litmus paper changes to a light pink or to a red. (It will not.) Leave the litmus paper in the water and give several pupils soda straws and have them blow bubbles (CO_2) into the water. Continue to blow bubbles *until a noticeable color change* occurs. Compare the results of these tests with those of the other acid tests. (The litmus paper placed in the vinegar and hydrochloric acid solutions will be a deeper shade of pink than the litmus paper placed in a carbonic acid solution. Carbonic acid is a weak acid.)

Discuss the most important sources of carbon dioxide in the physical and biological environment. (*Living things* and *decaying and decomposing dead plants and animals* are major sources.) Plan experiments that may provide evidence that decomposing plants and animals release carbon dioxide which can cause carbonic acid to form in water. This is one experiment that can be done. Collect a few fleshy plant leaves that have fallen to the ground. Moisten the leaves and place them in a container that has a screw-type cover. Add enough water to cover the bottom of the container. Shake the container and test the water in it with blue litmus paper. (It is unlikely that any color change will occur.) Screw the lid on the container and place it in a warm, dark place. Check the water in the container daily to discover whether the litmus paper indicates the presence of an acid. (On the second day, there should be a slight color change. After the third or fourth day, the pupils should both see and hear that the decomposing leaves are releasing a gas.) At the conclusion of the experiment, compare the results of this test with the color change that occurred in the vinegar and hydrochloric acid solutions.

Discuss how the mild carbonic acid (H_2CO_3) present in water attacks surface minerals; how it dissolves some of the minerals; how it combines with minerals like calcium, magnesium, and iron to form soluble calcium, magnesium, and iron *carbonates;* how these soluble carbonates are transported and finally precipitated in a solid form as *carbonates*. This formation of carbonates by the process of chemical weathering is called *carbonation* (see Table 7.2).

If there are cold or hot mineral springs in the area, obtain some water from them. Place the water in a clean glass container. After the water has evaporated, observe the mineral (chemical) deposit left in the container. Sea water or bottled mineral water also can be used in this experiment.

Bring to school a tea kettle which has been used for a long time. Examine the inside of the kettle for mineral deposits. Be sure that the pupils understand that the deposits on the inside of the tea kettle came from the water which was boiled in it.

Ask the pupils to think of a chemical test, which they have previously used, which may help them now to identify at least one of the minerals deposited in the kettle. (Much of the mineral deposit will consist of calcium carbonate, *lime*.) The pupils should be able to recall that a dilute solution of hydrochloric acid (5–10%) is used to test for the presence of calcium carbonate. All carbonates effervesce in a hydrochloric acid solution and give off carbon dioxide (CO_2). Remove some of the deposit from the inside of the kettle and test it with acid. What happens when this acid contacts the deposit? What does this show? (Bubbles can be seen. They show that the deposit from the kettle contains lime, $CaCO_3$.)

Also put a few drops of hydrochloric acid on the precipitated minerals from spring water to find out if they too are carbonates. (If they effervesce and release bubbles of carbon dioxide gas, they are carbonates.) Have the pupils look at the chemical formulas of carbohydrates to decide the source of the released CO_2. (It is released from the CO_3 in the carbonate formula.)

Ask some pupils to look up and report to the class information about these carbonates, calcite ($CaCO_3$), magnesite ($MgCO_3$), siderite ($FeCO_3$), azurite, and malachite. Test samples of each with drops of hydrochloric acid. Do they effervesce? (They should.)

Help the pupils build the concept that both the physical and chemical weathering that cause changes in rocks are constructive processes. Without weathering, the land masses on the earth would be bare, hard rocks. There would be no soil and consequently no plant and animal life. Weathering of rock has contributed also to such valuable mineral deposits as ores of aluminum, copper, iron and manganese. Weathering also indirectly results in deposits of sand, gravel, clay. Physical weathering causes fragmentation of exposed rocks and chemical weathering attacks some of the minerals in exposed rocks. Both physical and chemical weathering occur as far down into the earth's crust as water and air can penetrate. Soil, clay, and sedimentary rock are porous. This porosity makes it possible for them to be penetrated by the weathering agents (oxygen, hydrogen, and carbonic acid). It also makes it possible for the chemical processes of *oxidation*, *hydration*, and *carbonation* to take place.

2. What major changes have occurred in the earth's surface in the past?

Discuss this problem with the class. Emphasize that the problem is one of *major* change in the *past.* Some pupils may suggest the great continental glaciers of the past that advanced and retreated over the northern areas; others may suggest the formation of mountain ranges as major changes.

Read about the great glaciers of the past in science books. Direct this reading with these three general questions: (1) Which regions in our country were affected by these great continental glaciers? (2) What changes did the glaciers make in the earth's surface? (3) About how many years have passed since the last continental glacier extended over the northeastern part of the United States (see Fig. 7.1)?

Discuss some of the following topics.

1. The regions that were affected by the great continental glacier.
2. V-shaped valleys that were rounded into U-shaped valleys.
3. Stream beds that were altered.
4. Lakes and waterfalls that were altered.
5. New lakes that were formed.
6. Rock debris that was transported and deposited.
7. Bedrocks that were smoothed, scratched, and grooved.
8. Mountains that were rounded, worn away, scratched, and grooved.
9. Gravel deposits that are glacial debris deposited in hills and ridges.
10. A time scale of the major events in the earth's history that shows when great glaciers were major forces changing the earth's surface.

If the class is planning to continue with the inquiries in this section, they should make a large blank chart of the earth's time scale (similar to Table 7.3) with only the headings and the third column containing the estimated number of millions of years ago on it, and hang this chart on the wall of the classroom. As the children study the major events in the earth's history, these events may be added. Begin by recording the major glacial events at 2,235, and 1,200 millions of years ago (see Table 7.3).

If your school is located in a glaciated region, take a trip to examine some of the changes caused by glaciation. Glacial gravel deposits are excellent sources for locating the wedged-shaped pebbles that were shaped by the friction of glaciers dragging them over bedrock. Erratic boulders that have been transported from other regions by glaciers are also evidence that a region has been glaciated. *Erratics* are boulders that are different from the bedrock formation

Table 7.3

MAJOR EVENTS IN THE EARTH'S HISTORY FROM ANCIENT TO RECENT TIMES

Eras Revolutions (uplifts)	Periods	Millions of Years Ago (estimated)	Physical Events	Life Development
Cosmic or *Azoic*		4000		Before life appeared on the earth
Archeozoic Laurentian Revolution		2000–2500	Rocks very old, greatly altered, and history obscure Adirondack Mts. Superior Highlands of north central United States Laurentian Highlands of Canada	Primitive life probable
Proterozoic Killarney Revolution		1200	Folding associated with igneous intrusions Oldest evidence of glaciation	Scanty record of primitive plants and animals Probable development of shells on invertebrates
Glaciation			Extensive lava flows	
Paleozoic Appalachian Revolution	Cambrian	550	Green Mountain disturbance	Age of invertebrate dominance Trilobites
	Ordivician	445	Taconic Mts.	First known fishes
	Silurian	375	Caledonian Mts.	Rise of land plants
	Devonian	350	Acadian Mts.	Age of fishes
	Carboniferous	315	Extensive coal-forming swamps	Large nonflowering plants
	Permian	235	Widespread glaciation Folding of Appalachian Mts.	Rise of reptiles
Mesozoic Laramide Revolution	Triassic	200	Igneous intrusions forming the Palisades (New Jersey) Extensive volcanic activity in New England, Pennsylvania, and New Jersey	First dinosaurs and primitive mammals
	Jurassic	168	Beginning of Sierra Nevada uplift	First birds First flowering plants, trees, and grasses Climax of land, sea, and air dinosaurs
	Cretaceous	130	Central Cordilleran uplift Early folding of Rocky Mts.	Extinction of dinosaurs
Cenozoic	Paleocene	60		First true mammals
	Eocene	50	Extensive volcanic activity in western United States	Apes appear
	Oligocene	40		
	Miocene	30	Formation of Alps and many other mountain ranges	Primitive horses
	Pliocene	10	Formation of Cascades, coast ranges, in western North America	
	Pleistocene	2	The great ice age Postglacial changes	Flowering plants dominate Man appears

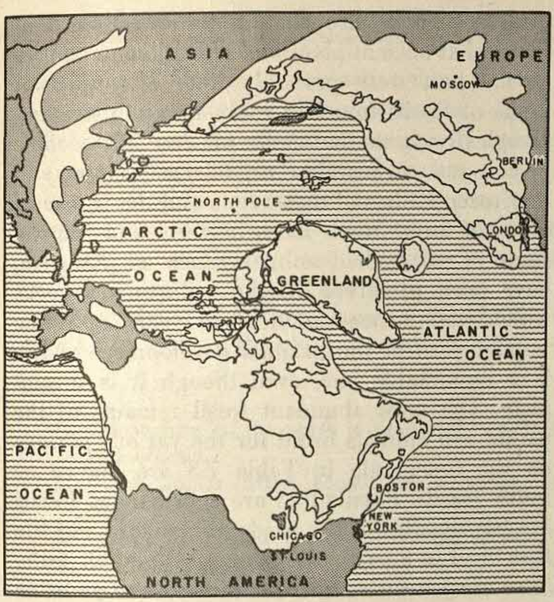


Fig. 7.1 Extent of glaciation in Northern Hemisphere. *From The Story of the Ice Age by Rose Wyler and Gerald Ames, Thomas W. Voter artist, Harper & Row, Publishers. Copyright © 1956 by Gerald Ames and Rose Wyler.*

found in the area. For example, a gneiss or a granite boulder found in a region containing sedimentary formations is an erratic.

Have the children plan some experiments to try to show how glaciers form from snow and how glaciers change a region. Some children who live in the North Temperate Zone have had many experiences with snowballs and may know that wet snow packs into hard balls of ice. Glaciers and icebergs are formed from tightly packed snow. If the class has not had this experience with snow, they will enjoy getting some of the frost that forms on the inside of freezing units and packing it into round ice balls with their hands.

Try to scratch rocks with ice cubes. Limestone or shale are good rocks to choose for this experiment.

Children who live in cold regions can take a trip in the early spring or during a thaw to observe how snow slides from roof tops and hillsides. These snow slides are miniature glaciers.

Build a model of a hill with a meandering (twisting) stream running down it and use an ice cube or a cake of ice for a glacier. Various sizes of sediments can be used in building the hill. Build the model in a metal tray and find a metal-lined sand table in which to stand the model when the class is ready to start the experiment. Place the ice in the stream bed at the top of the hill. Observe the ice as it slides down the stream and note the changes that occur. (This miniature glacier should widen the stream bed and straighten the curves in the meandering stream.)

Find out when the major mountain ranges were formed. Enter this information on the chart the children are making of the important events in the earth's history. Take this opportunity to discuss how old the rocks of the earth are, how long ago the major mountain ranges were formed, and how much rock must have been eroded away during the years that have passed since the mountains were formed.

3. How old is the earth?

From the information on mountain building, added to the chart in the last inquiry, note that the Laurentian Highlands of Canada, the Superior Highlands of the north central United States, and the Adirondack Mountains of New York State are at least 2000 million years old.

Because the measurement of geological time in thousands, millions, and billions of years has very little meaning to children, they need help in comprehending these figures. Ask them to calculate the number of seconds in an hour, a day, and in a 365-day year. (An hour has 3600 seconds. A day has 86,400 seconds. A year has 31,536,000 seconds.) Help the children to round off 31,536,000 to 30,000,000 (30 million) and to realize that if they were to count at the speed of one number every second, day, and night for a whole year, they would have counted to approximately 30 million. Using this method of counting, they would need 10 years to count to 300 million, 60 years to count to 1,800 million, and about 63 years to count to 2000 million. *If each year of the earth's history were as short as one second,* it would take 1 year of counting to count to the Miocene Period (30 million years) when the Alps were formed; 10 years to count to the Carboniferous Period (300 million years) when the coal-forming swamps were present; and 63 years to count to the Archeozoic Era (2000 million years).

The most reliable method for reckoning the earth's age is to determine the age of its rocks. For this purpose, scientists use a delicate electronic instrument, sometimes called an *atomic clock.* This instrument has dated pitchblende (one kind of uranium ore found in igneous rocks) taken from a rock formation on the Winnipeg River in the province of Manitoba, Canada as 2300 million years old. The age of this Canadian pitchblende identifies it as an Archeozoic rock.

By this same method, rock formations found in Southern Rhodesia have been dated as 3300 million years old. Astronomers believe that meteorites were formed at the same time the solar system was formed. Careful measurements of the radioactivity in meteorites indicate that they are about 4500 million years old.

The children also should learn that all things that were once alive contain radioactive carbon and can be dated by a similar method. The age of an Egyptian mummy, the charcoal from a caveman's fire, ancient bones, or even the pollen from plants that lived long ago can be determined electronically.

4. Why is the earth's history divided into eras and periods?

Help the pupils make a time scale like the one in Table 7.3. Discuss the physical changes that occurred in each of the eras. Explain that the Cenozoic Era includes the present time and is not yet ended; therefore, it has no major revolution. Also explain that during each of these revolutions, certain mountains and highlands of the world were uplifted. Under the column of physical events on their chart, have them write the names of the mountains and highlands (see Table 7.3 for these) opposite the era and period in which they occurred.

Divide the children in the class into three committees. Ask one committee to read about the plants and animals that were typical in each era and period. Also ask this group to find information to support the claim that these plants and animals lived in the past. This group should put the information they find in the last column of the time scale chart made by the class. Books and encyclopedias contain many pictures of the fossils found in rock formations of these periods. These reference books also contain reproductions that show what ancient plant and animal communities of the past were probably like. The different kinds of fossils found in rocks range in size and complexity from the shells of tiny microscopic protozoans and plantlike organisms (diatoms) to the frozen bodies of mastodons and the trunks of gigantic forest trees. Even bacteria and impressions of soft-bodied animals, such as jelly fish, have been preserved in the sedimentary rocks which were formed millions of years ago. The fossil record of the gradual development of life is a remarkable one, even though it is incomplete. The most abundant fossil remains of the plants and animals listed for the various periods on the time scale in Table 7.3 are known as *index fossils.* Fossils that are called index fossils are the remains of the predominant forms of life that lived in a particular geological period. Trilobites are known as index fossils of the Cambrian Period; dinosaurs, as index fossils of the Jurassic Period. This committee should be able to deduce three basic assumptions from their reading:

1. **Simple plants and animals, such as algae and protozoans, are believed to have developed before more complex ones.**
2. **Younger sedimentary rock formations lie on top of older rock formations.**
3. **Geologists use change in the dominant form of life as an indication that one period has ended and another has started.**

Assign to the second committee the problem of locating on a world map the mountains and highlands listed on their chart. It would be helpful to the rest of the class, if the committee would first make an outline map of the world and locate the regions in which mountains were formed during the five eras. A crayon of different color can be used to identify the mountain formation of each era. This committee also could find the present maximum heights above sea level of these ranges and compare them to the age of the mountains. They also should try to find another clue that indicates to geologists when both periods and eras end. (Eras end with the termination of major mountain-building activities. Periods end with the termination of minor uplifts of the land and the gradual submergence of the land under the sea.)

A third committee can be assigned the problem of identifying and locating the active volcanoes of the world. Volcanoes are active during mountain-building activities. This committee should collaborate with the second committee in making the world map and be allowed to use a sixth color, preferably red, to locate on the map each of the active volcanoes. Ask this group to decide whether active volcanoes are in regions of recent or ancient uplift. (Recent uplift.)

When the committees have finished their reports, be sure all the children understand that:

1. The surface of the earth is alternately uplifted and eroded.
2. Major uplifts often consist of a series of minor uplifts.
3. Usually the highest mountains are the youngest.
4. Volcanic activity is located in regions where uplift is still taking place or in regions where there are young mountains.
5. When long ages of *major uplift* end and are followed by either *erosion and glaciation,* or both, geologists believe an *era* is closed.
6. When *minor uplifts* end and the *dominant forms of life change,* geologists believe a *period* is ended.
7. The earth is very old.
8. The earth and life upon it are constantly changing.

During a review of this section, questions similar to the following can be used.

1. Where are sedimentary rocks formed? (Mostly on the bottoms of oceans.)
2. If index fossils from any one of the periods of the earth's history are found in the rock formations of a region, what physical event occurred during this period? (An ocean must have covered the region during the time these sediments were being laid down.)
3. If evidence of erosion is found between layers of sedimentary rock formations, what physical events occurred in this region? (A minor uplift.)
4. If a region has rock formations that contain abundant fossils of dinosaurs and imprints of their tracks, what do we know about this region? (These rocks were formed during the Triassic Period when dinosaurs were the dominant land animals.)
5. If a region contains no fossil record more recent than the Cambrian Period, what do we know about this region? (It probably has been above sea level since the end of the Cambrian Period.)
6. If a region contains no exposed sedimentary rock formations, what may be true of this region? (The sedimentary rocks may have been worn away or covered by recent lava flows or by glaciated soil and sediments.)
7. Where are sedimentary rocks being formed today? (In the mouths of rivers, lakes, oceans, and swamplands.)
8. What must happen to the sedimentary rocks that are being formed today if they ever are to be visible on the land? (The submerged rock formations must be uplifted by mountain-building activities.)

5. Which forces and changes are men attempting to control? What attempts are men making to wisely utilize the earth's resources?

Discuss man's attempts to control the physical forces that change the earth's surface. Also discuss his attempts to wisely utilize the earth's resources. Some of the subjects for discussion may include progress that has been made in the following areas:

1. Controlling floods;
2. Reclaiming land;
3. Reducing soil erosion;
4. Increasing water supplies for public use;
5. Developing substitutes for depleted fuels and minerals;
6. Making long-range weather forecasts;
7. Controlling weather patterns;
8. Breaking up hurricanes or typhoons at their source;
9. Predicting earthquakes and volcanic eruptions;
10. Changing the course of lava flows;
11. Utilizing the food and mineral resources in the sea;
12. Expanding the use of atomic power;
13. Utilizing the energy of the sun.

If possible, take trips to observe man's attempts to control physical forces and changes.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. There are two major kinds of forces that change the earth's surface—they are physical and chemical forces. There are many physical forces that cause weathering. There are three major forces that cause chemical changes in the earth's surface—they are oxidation, hydration, and carbonation. Both the physical and chemical forces which cause changes to the earth's surface are constructive processes. Life could not exist on the earth without physical and chemical weathering. Physical weathering causes the fragmentation of exposed rock and chemical weathering decomposes some of the minerals in them.

2. The major events that altered the earth's sutface in the past were glaciers and uplifts caused by mountain building. Weathering, gravity, friction, and erosion have been operating on the earth for at least two billion years.

3–4. The estimate of the earth's age is made by counting the particles emitted from atoms of uranium contained in what are thought to be the oldest known igneous rocks. Eras in the earth's history end with the termination of major mountain-building activities. Periods end with the termination of minor uplifts of the land and a change in the dominant forms of life. Throughout the earth's history, mountain ranges have been slowly uplifted and slowly eroded.

The fossil record found in sedimentary and metamorphic rocks provides evidence that causes scientists to believe that the earliest forms of life were very simple and that the more complex forms of life appeared later in the earth's history. Sedimentary rocks contain valuable records that geologists use to piece together the earth's history. Younger sedimentary rocks lying on top of older rock formations indicate that various regions of the earth have emerged above sea level and submerged below sea level many times during the earth's history.

5. Man is learning how to control some of the physical and chemical forces which change the earth's surface. He is also learning to wisely use and conserve the earth's resources.

Chapter Eight

The Earth's Atmosphere

Weather Changes

INQUIRIES

1. How can we find out whether air is real?
2. Where can we find air?
3. How can we find out whether air fills things?
4. What is wind?
5. What causes air to move?
6. How can we measure air temperature? How does a liquid thermometer work?
7. How can we find out whether air has weight?
8. Which weighs more—warm air or cool air?
9. What happens if some air is cool and some is hot?
10. How can we learn whether there is water in the air?
11. How does water get into the air?
12. How does the weatherman measure precipitation?
13. How can we find out whether air has pressure?
14. How does the weatherman measure air pressure?

15. How does the weatherman measure wind direction and speed?

16. How does the weatherman measure the amount of water vapor in the air?

17. What is meant by the terms *high-pressure* and *low-pressure areas*? What causes these areas?

18. What are warm and cold fronts? How are they formed?

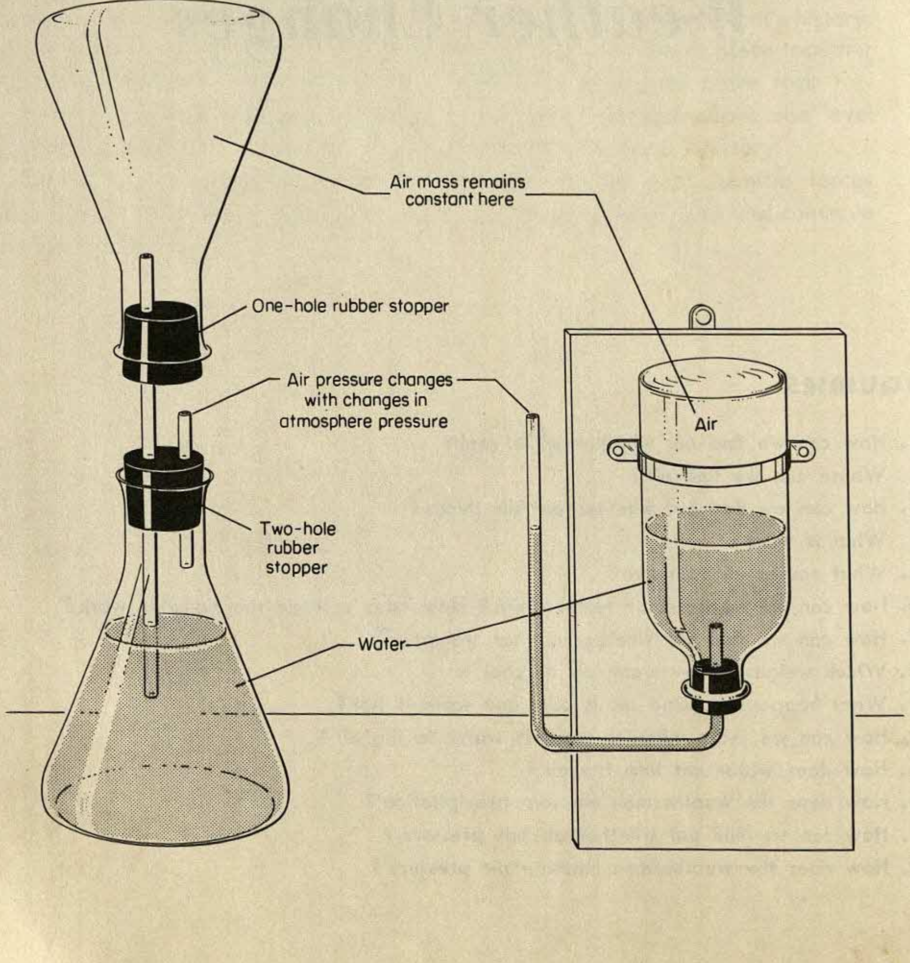
19. What are some records the weather bureau uses to make forecasts?

20. What are some recent discoveries and inventions that may make it possible to control weather?

This is a skeletal chapter. It suggests a sequence of inquiries, includes a few useful figures and tables, and ends with a summary of scientific findings. Teachers and pupils may wish to substitute their own inquiry sequence for the one suggested here.

No activities are included in this chapter. They were omitted in order to give teachers and pupils the opportunity to plan and carry out their own investigations. Together they can plan the activities and experiences and, in so doing, build their own weather resource unit. It also provides the opportunity for teachers and pupils to select those activities which require them to repeatedly *practice using the process skills.*

Fig. 8.1 Two different models of water barometers.


Air mass remains constant here
One-hole rubber stopper
Air pressure changes with changes in atmosphere pressure
Air
Two-hole rubber stopper
Water

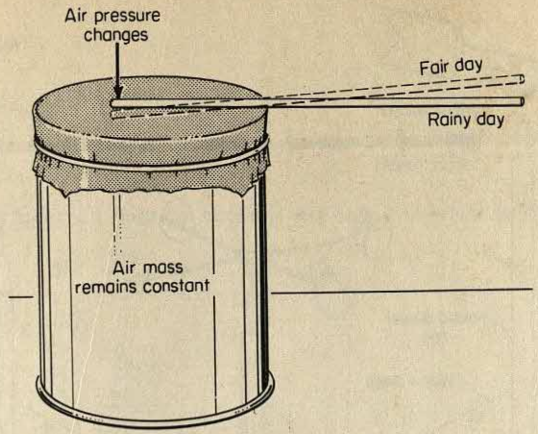
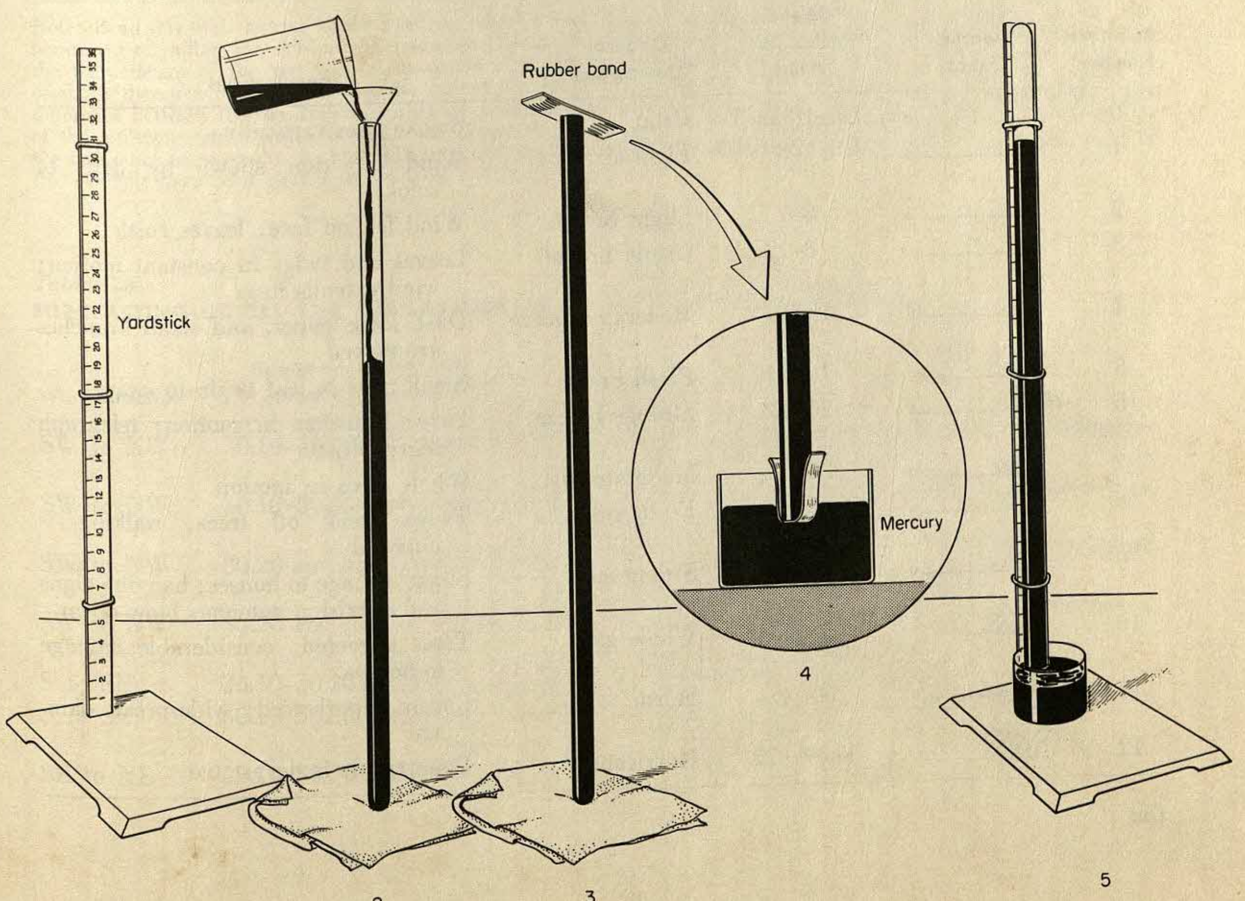


Fig. 8.2 How an air barometer works. Set up this barometer on a day when the atmospheric pressure is high. The amount of air pressure inside the can remains about the same. The air pressure outside the can changes. On a rainy day the pointer on the barometer falls. To make this model cut the neck from a large balloon. Stretch the balloon over the top of a large tin can and fasten it with a rubber band. Glue a soda straw to the center of the stretched balloon.

Fig. 8.3 Five steps in making a mercurial barometer: (1) Fasten a yardstick to the rod of a ringstand. (2) Place several thicknesses of cloth on the floor; hold barometer in an upright position on the cloth; slowly fill tube with mercury; tamp tube gently, as mercury descends into tube, to help air escape. (3) When tube is filled with mercury, stretch a wide rubber band tightly across the top of the tube; hold rubber band securely and invert tube into a shallow container of mercury. (4) When tube has been lowered below the surface of the mercury in the dish, remove rubber band; lower tube until it touches the bottom of the dish and place it on ringstand. (5) Fasten barometer tube and yardstick securely to the rod of the ringstand; raise the end of the yardstick to the level of the surface of the mercury in the dish.



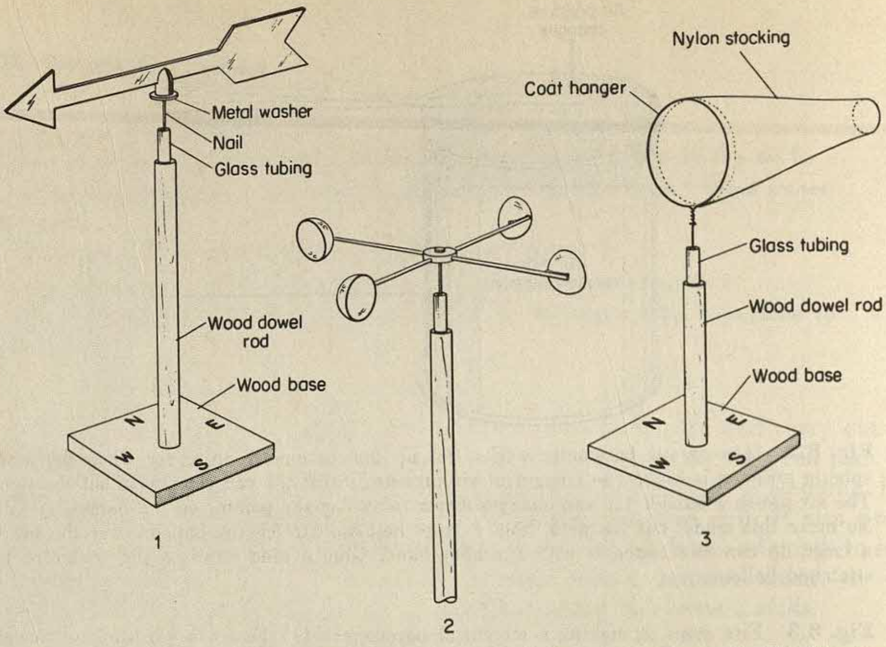


Fig. 8.4 Simple instruments that can measure wind direction and speed. (1) Weather vane—find point at which cardboard arrow balances; insert nail through cardboard into glass tubing. (2) Wind sock—sew nylon stocking to frame made from a coat hanger; insert wire into glass tubing. (3) Anemometer—cut two ping pong balls in half; glue to wooden cross pieces as shown in diagram; insert nail through cross pieces into glass tubing.

Table 8.1

HOW TO ESTIMATE WIND SPEED

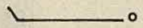
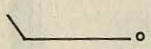
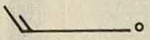
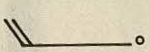
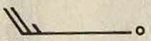
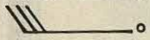
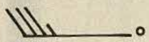
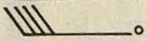
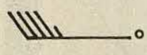
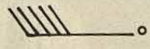
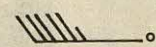
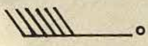
Beaufort Number	Weather Maps	Speed (miles per hour)	General Description	Specifications
0		Less than 1	Calm	Smoke rises vertically
1		1–3	Light air	Wind direction shown by drift of smoke
2		4–7	Slight breeze	Wind felt on face; leaves rustle
3		8–12	Gentle breeze	Leaves and twigs in constant motion; wind extends flags
4		13–18	Moderate breeze	Dust, loose paper, and small branches are moved
5		19–24	Fresh breeze	Small trees in leaf begin to sway.
6		25–31	Stronge breeze	Large branches in motion; telegraph wires whistle
7		32–38	Moderate gale	Whole trees in motion
8		39–46	Fresh gale	Twigs break off trees; walking is impeded
9		47–54	Strong gale	Slight damage to houses; hanging signs and television antennas blow down
10		55–63	Whole gale	Trees uprooted; considerable damage to houses
11		64–75	Storm	Rarely experienced; widespread damage
12		above 75	Hurricane	Countryside is devastated

Table 8.2

RELATIVE HUMIDITY TABLE: Percentage of Water Vapor in the Air

(Barometric Pressure, 30.00 inches)

Air Temperature, °F	Difference in Fahrenheit degrees between dry-bulb and wet-bulb thermometers 1	2	3	4	6	8	10	12	14	16	18	20	25	30
0	67%	33%	1%											
5	73	46	20											
10	78	56	34	13%										
15	82	64	46	29										
20	85	70	55	40	12%									
25	87	74	62	49	25									
30	89	78	67	56	36	16%								
35	91	81	72	63	45	27	10%							
40	92	83	75	68	52	37	22	7%						
45	93	86	78	71	57	44	31	18	6%					
50	93	87	80	74	61	49	38	27	16	5%				
55	94	88	82	76	65	54	43	33	23	14	5%			
60	94	89	83	78	68	58	48	39	30	21	13	5%		
65	95	90	85	80	70	61	52	44	35	27	20	12		
70	95	90	86	81	72	64	55	48	40	33	25	19	3%	
75	96	91	86	82	74	66	58	51	44	37	30	24	9	
80	96	91	87	83	75	68	61	54	47	41	35	29	15	3%
85	96	92	88	84	76	70	63	56	50	44	38	32	20	8
90	96	92	89	85	78	71	65	58	52	47	41	36	24	13
95	96	93	89	86	79	72	66	60	54	49	44	38	27	17
100	96	93	89	86	80	73	68	62	56	51	46	41	30	21

Note: Read this table as you would a mileage chart which lists the distances between cities. Determine the air temperature by reading the dry-bulb thermometer. Locate this temperature in the left-hand column of the table. Read the temperature of the wet-bulb thermometer and determine the difference between this reading and that of the dry-bulb thermometer. Read across the top of the table to the column that indicates the number of degrees of difference between the dry-bulb and wet-bulb readings. The percentage of relative humidity is that figure to the right of the air temperature which is under the degree of difference. For example, if the air temperature is 70°F and the difference between the dry-bulb and wet-bulb readings is 4°F the relative humidity is 81%. (The figures used in this example have been circled on the table.)

Table 8.3

FORECASTING GUIDES FOR THE LAYMAN: Wind and Barometer Indications

Wind Direction*	Sea-level Barometric Pressure (inches)	Character of Weather Indicated
SW to NW	30.10–30.20 and steady	Fair for one to two days with little temperature change
SW to NW	30.10–30.20 and falling rapidly	Fair followed within 2 days by warmer temperature and rain
SW to NW	30.20 and above and stationary	Continued fair with no marked temperature change
SW to NW	30.20 and above and falling slowly	Fair with slowly rising temperature for 2 days
S to SE	30.10–30.20 and falling slowly	Rain within 24 hours
S to SE	30.10–30.20 and falling rapidly	Wind increasing in force with rain within 12–24 hours
SE to NE	30.10–30.20 and falling slowly	Rain in 12–18 hours

Table 8.3 **(*cont.*)**

SE to NE	30.10–30.20 and falling rapidly	Increasing wind and rain within 12 hours
E to NE	30.10 and above and falling slowly	In summer, with light winds, rain may not fall for several days; in winter, rain within 24 hours
E to NE	30.10 and above and falling rapidly	In summer, rain probable within 12–24 hours; in winter, rain or snow, with increasing winds
SE to NE	30.00 or below and falling slowly	Rain will continue 1 to 2 days
SE to NE	30.00 or below and falling rapidly	Rain with high winds, followed within 36 hours by clearing, and in winter by colder temperature
S to SW	30.00 or below and rising slowly	Clearing within a few hours and fair for several days
S to E	29.80 or below and falling rapidly	Severe storm soon, followed within 24 hours by clearing, and in winter by colder temperature
E to N	29.80 or below and falling rapidly	Severe northeast gale and heavy precipitation; in winter, heavy snow followed by a cold wave
Going to W	29.80 or below and rising rapidly	Clearing and colder

Note: This table, prepared by the U.S. Weather Bureau, is a general summary of observations taken all over the country. It is, therefore, an average and will not apply to your back yard without some alteration. The pressure readings in particular differ in different localities. This table, however, will help you to correlate wind and barometric tendencies with changes in the coming weather.

A *rapid* rise or fall of pressure is one equal to or greater than 0.45 to 0.90 inches (2 to 3 millibars) in three hours. A *slow* rise or fall of pressure is less than this amount, depending again on the locality and circumstances.

* A NW wind blows from the Northwest.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1–3. Air is real because we can feel it and see the things it can do. Air is all around us. It is found in water, soil, in us, and in many things. Air fills things. Containers which look empty are filled with air.

4–6. Wind is moving air. When air moves fast, it causes strong winds. When air moves slowly, it causes gentle breezes. When air is still, there is no wind. Air expands when it is heated. Air contracts when it is cooled. Heating air causes it to move. Thermometers measure air temperatures. Air temperatures vary. The process of heating and cooling air causes it to move.

7–9. Air has weight. Warm air expands and occupies more space. Cool air contracts and occupies less space. Cool air weighs more than warm air. Warm air rises and is replaced by cool air. Cool air and warm air mix.

10–12. Even though it cannot be seen, water is present in the air. Water that is wet and can be seen is called a *liquid.* Water in the air that cannot be seen is called a *vapor.* When water changes from a liquid to a vapor it evaporates. Water evaporates faster in a warm place than in a cold place. Water evaporates faster if it covers more surface. Water also evaporates faster if the air above it is moving. A rain gauge is used to measure precipitation.

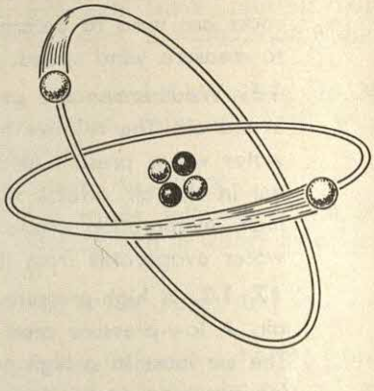
13–15. Air has pressure. Air presses in all directions. A barometer is used to measure atmospheric pressure. The barometric pressure is higher on a clear, cold day than it is on a hot, humid, or rainy day. Weather vanes and wind socks are used to determine the direction of the wind. Anemometers are used to measure wind speed.

16. Weathermen use psychrometers to determine the amount of water vapor in the air. The relative humidity of the air is expressed in the percentage of water vapor present at a given temperature. The amount of water vapor present in the air affects the comfort of people. When the relative humidity is high, evaporation occurs more slowly. Evaporation is a cooling process. When water evaporates from the skin, heat is removed.

17–18. A high-pressure area is a region where there is a cool mass of dry air. A low-pressure area is a region where there is a warm mass of humid air. The air mass in a high-pressure area tends to move toward the mass of air in low-pressure areas. Unequal heating of air over large land masses and bodies of water is one cause for the difference in barometric pressure in high- and low-pressure areas. A *cold front* is the boundary where a *moving* mass of cool air meets a mass of warmer air. A *warm front* is the boundary where a *moving* mass of warm air meets a mass of cooler air.

19. The daily U. S. Weather Bureau forecast is an analysis of weather conditions that will probably exist during the next 24 hours. These forecasts are based upon past records made when similar atmospheric conditions existed, weather trends during several days previous to the forecast, reports from regional weather stations, and weather observations made by instruments in weather satellites. Hundreds of regional weather stations located throughout the United States and at sea send daily reports of weather conditions in their region to the U. S. Weather Bureau. The percentage of accuracy in weather forecasts varies in different regions.

20. Man is learning how to use chemicals, electronic devices, nuclear energy, and ultraviolet light to control weather patterns. The results of man's progress in meteorology and travel in space lead scientists to believe that climatic control may be possible. If put into practice, climate control is likely to create problems of human relations and welfare which will require much foresight and wisdom to resolve.



Chapter Nine

The Composition of Things

Solids, Liquids, and Gases

INQUIRIES

1. What are some of the ways liquids, gases, and solids differ?

2. How can solids be changed into liquids, liquids into gases, gases into liquids, and liquids into solids? What causes them to change and what are these changes called?

3. If enough heat to change solids, such as iron or copper, into liquids is not available, what other changes can be observed?

4. What causes liquids to expand and contract?

5. What causes gases to expand and contract?

1. What are some of the ways liquids, gases, and solids differ?

Arrange a time and a place for each pupil to personally try the following experiences with a liquid. A metal-lined sand table makes a useful work area. Hopefully any spilled water will be confined to the sand table. Observe the children as they work. Listen to them talk about what they are doing and seeing. Encourage the children to exchange their interpretations and explanations with each other. Collect and place on the sand table a square glass dish, a round glass dish (Pyrex loaf pan and pie plate), a glass, a quart milk bottle with a tight cover, a tall olive bottle, and other odd-shaped glass containers. Clear glass dishes make it easier for everyone to see what happens. Place a pitcher of water and a measuring cup on the sand table.

Watch for the pupils to use the materials on the sand table in some of these ways. Water will be poured *from one container to another.* The measuring cup will be used to put an equal amount of water into the variety of containers. Comments will be heard about the way the water looks (shape) in the various containers.

Watch for some child to put water in an odd-shaped container, such as a milk bottle, which he covers, seals, or stoppers and then holds right-side up, up-side down, on its side, and at interesting angles.

When the children finish their personal investigations, arrange for them to share their observations. As they discuss their experiences, they should agree that *water has no shape of its own;* that *it takes the shape of each container;* and that *it tends to keep the shape of the container.* Also at this time introduce and use the word *liquid.* Ask the children to name other liquids and to speculate whether these liquids would do the same things water did. If the scientific findings need further reinforcing, the experiences could be repeated with a different liquid.

Clean and dry the containers which were used in the previous investigations. Add to the sand table a medium-sized aquarium. Fill it to within 4 inches of the top. Allow the children to experiment with the "empty" containers in this tank of water. Wait and watch for the children to discover that the containers are not "empty"; that something comes out of them into the water; and that this something is air.

Add a box of soda straws to the working materials. Ask the children why they should not drink water from the aquarium with these straws. (They have had their hands in the water in the aquarium.) Also remind them never to use a soda straw after it has been used by someone else.

Watch how the pupils use these straws to blow air bubbles into the water in the aquarium. If the children find a small bowl of liquid soap in the work area, they will quickly discover they can blow soap bubbles with the soda straws. Watch *for some child to discover* that the air, which has been blown into the soap bubble, can be carefully sucked out of the bubble to cause it to become smaller.

Provide some lengths of rubber tubing. The pieces of tubing should be about 24 inches long. Show the children *only* that their soda straws can be fitted into the end of the rubber tubing to provide a clean personal mouth piece. Tell them they *must not put the rubber tubing directly into their mouths.* Insist on these health controls. Otherwise, permit free exploration. Some children will soon discover how to blow air into a container submerged in the aquarium water.

Provide a time for the children to relate and interpret their experiences. They will know they have been using air. If water is a *liquid,* what is air? It is not a liquid. The word *gas* needs to be introduced, discussed, and used. In the discussion the children may be expected to supply the information that there is oxygen, carbon dioxide, nitrogen, etc. in the air. Perhaps some child can tell of seeing (maybe on TV) people being given oxygen to breathe. Other children will know that tanks of gases are used by scuba divers. They may know also that carbon dioxide gas is used as a fire extinguisher. They know that racing balloons, blimps, weather balloons, and escaping toy balloons are filled with a gas which causes them to rise in the air. They know about gas stoves, about the exhaust gases from automobiles, and about tear gas. The variety of children's suggestions will provide evidence that can be generalized into initial statements such as: There are many different gases. Gases have many uses. Air is a *mixture* of gases.

Purchase a large bottle of ginger ale. Chill it. Provide a toy balloon which has been repeatedly inflated in order to stretch it. Obtain a one-hole rubber stopper which will fit into the open neck of the ginger ale bottle. Fit the one-hole stopper with a short piece of glass tubing onto which a length of rubber tubing is added. A bottle opener is also needed. In this class activity the children can observe and discover that:

1. Bubbles can be seen in the ginger ale when the bottle is gently shaken.
2. If the neck of the balloon is stretched over the open neck of the ginger ale bottle, the balloon will start to inflate.
3. The balloon feels as if there is a gas inside it.
4. Whatever is in the balloon came from the liquid in the bottle.

5. **If the one-hole rubber stopper with the attached rubber tubing is fitted into the open neck of the full ginger ale bottle, and if the free end of the rubber tubing is placed in water, bubbles of gas will leave the ginger ale, and go through the tubing into the water.**

6. **The gas escaping from the ginger ale through the tube will displace the water in a small inverted submerged container. If this container of gas is tightly sealed with a screw top *while the container is still submerged,* the gas can be kept in the container.**

7. **There is a gas in ginger ale.**

8. **Other soft drinks contain gas.**

Empty the ginger ale bottle. Demonstrate that a gas can be made in another way. Put about three tablespoonfuls of baking soda in the bottom of the empty ginger ale bottle. Add just enough water to wet the baking soda. Finally pour in about ¼ cup of vinegar and quickly stopper with the one-hole stopper with the attached tubing. Demonstrate the presence of gas by putting the free end of the tube in water. Allow and encourage the pupils to repeat this preparation of a gas and to use it to fill balloons, displace water in small inverted submerged containers and to seal and save a small screw top container full of this gas.

Show the children still another way to make a gas in the ginger ale bottle. Break a yeast cake into the bottle. Add two teaspoonfuls of sugar and finally ½ cup of lukewarm water. Stopper with the one-hole stopper and tubing. Place the free end of the tube under water. Put the complete set-up in the sun. Watch. Encourage the pupils (with more yeast, sugar and water if necessary) to repeat the earlier ways to fill a balloon with gas, to displace water with a gas, and to collect and seal the gas in a container.

Without opening the three sealed containers of collected gas, have the children observe and compare the gases from the ginger ale, from the baking soda, water and vinegar, and from the yeast, sugar and warm water with a sealed container of air. The children should not be able to observe any difference. However, they should conclude that each contains a gas. They may ask if all four jars contain the same kind of gas.

Let the pupils discuss, read, and search for ways to test the gases in the four containers. The children may find how to do these two simple tests. (1) Obtain the long wooden kind of matches. Light a match. Quickly open a sealed container of gas, gently lower the flame into the jar. Remove the match and quickly reseal the jar. *This activity with lighted matches needs to be closely supervised.* What happens? In three of the jars the flame is extinguished. In one the flame continues to burn. The four jars of gases do not all react in the same way to the flame test. (2) If the children's reading has provided the information that *limewater* will change from a clear watery liquid to a milky-appearing liquid when carbon dioxide gas is mixed with it, let them test the containers of gas with limewater. Limewater can be bought at drug stores. It is inexpensive and safe to use. It is used as a medicine for babies. Open each container, quickly add one teaspoonful of limewater and reseal. Shake to mix the gas with the limewater. The children should observe the milky color change, which occurs to the limewater. The limewater added to the container of air should be *less milky in color* than that in the other three jars. What conclusions can be formed? (There is some carbon dioxide gas in air. The gas from the ginger ale, from the baking soda, water and vinegar, and from the yeast, sugar and warm water was carbon dioxide. Carbon dioxide gas extinguishes fires and turns limewater milky. There is not enough carbon dioxide gas in air to cause air to extinguish a flame.)

Provide time and encouragement for pupils, on their own, to substitute limewater for water in some of the earlier experiments in this inquiry. Urge the children to speculate how the carbon dioxide gas produced by yeast is useful in bread making.

Have some pupils repeat the making and testing of carbon dioxide gas in this demonstration. Obtain two large-mouthed, gallon, glass jars. With melted wax, *secure* a candle to the bottom of each jar. The candles should be the same length and short enough so that when they are lighted their flames will be below the top of the jar. Light the candles *in both jars. To one jar only,* add baking soda, a little water and some vinegar. Be careful to drop these three ingredients into the jar without their touching the flame. What happens? (The flame in this jar is extinguished.) *Be sure the foaming chemicals do not touch the flame.* (The flame in the other jar continues to burn.) Light a match. Try to relight the candle. What happens? (The flame on the match *is* *extinguished* as soon as it dips into the jar of gas.) Repeat every few seconds. On which try can the candle be relighted? Why? (The carbon dioxide gas did not stay in the open container. Most gases will not remain in an open container.)

Ask the children to compare the characteristics of gases with the characteristics of liquids. They can conclude (1) that both liquids and gases have no shape of their own and (2) that both liquids and gases will take the shape of the container into which they are placed, but (3) whereas *liquids tend to keep the shape* of an open container, *gases tend to escape rapidly* from open containers.

Collect solid objects which are small enough to be put into each of the same containers which were used in the previous experiences with liquids and gases. There should be enough of these solid objects, which are just alike, so that the children can put the same kind into each container. Marbles of the same size might be a good choice. Let the children manipulate the solid objects. As they work listen for them to suggest how the characteristics of solids vary from those of liquids and gases. During this inquiry into the characteristics of liquids, gases, and solids, comments like these may be made spontaneously by children: "Solids stay where we put them. They don't have to be kept in a dish. I think they look the same all the time. Marbles stay round. Not all solids are round. Solids can have all kinds of shapes. Round solids stay round and square solids stay square. I noticed the shapes didn't change."

About liquids they may say things like this: "Liquids spill. I think they are 'runny' things. We have to keep them in something. The water spread out in the pie plate. It looked tall in the olive bottle. It looked different in the milk bottle every time we turned the bottle a different way. Liquids can be any shape. They don't have any shape of their own. They are shaped like the things we put them in. The dishes and bottles shape the water."

About gases they may say: "Gases are funny. I couldn't see any of it. I saw the candle flames go out. Something did it. I think a gas did it. Air is a mixture of gases. We can't see air either. I know it wasn't air that put the fire out because candles burn in air. I couldn't see any shape. I don't think a gas has a shape of its own. The gas we made didn't stay in the containers very long. Maybe it didn't stay long enough in the dishes to become shaped like them. We kept the gas in a bottle when we put a tight cover on the bottle."

Statements like these also may be heard: "Ice has a shape; but it's water. Water won't stay in a bottle; it evaporates." These *statements of protest* are the children's way of opening up the next inquiry.

2. How can solids be changed into liquids, liquids into gases, gases into liquids, and liquids into solids? What causes them to change and what are these changes called?

Ask the class to suggest solids, liquids, and gases which they have seen change from one form to another. The list will be surprisingly extensive.

Arrange *work groups of six pupils or less.* Ask each group *to plan and invent some experiences* which they think can clarify this problem. *When there is any question of safety, supervise their experimentation.* However, if they have selected materials, with which it will be safe for them to work, *allow them to try out their planned inquiry independently.*

Children may plan inquiries similar to those in the following list. Different children may plan similar ones or they may very well plan inquiries which are quite different. *Encourage originality.*

1. Single ice cubes (solids) are tied and sealed into breadwrapper-sized, plastic food bags and are moved back and forth from freezing to very warm temperatures in order to observe that *solid* ice can change to *liquid* water and from *liquid* water to water vapor—a gas. They also can change water vapor to liquid water and back to ice. The variations children may propose and try are the results of their critical and creative thinking.
2. Sugar is melted (solid to liquid) and poured into a pan to harden (liquid to solid).
3. Butter is changed from a solid to a liquid and back again to a solid.
4. Ice cream is melted and refrozen.
5. Two small pieces of lead, which are approximately the same size, are obtained. One piece is melted in a metal can. What happens? (It

melts into a liquid and changes shape.) Some of it is poured drop by drop into cold water. The rest is poured onto a cold metal plate. What happens? (The molten lead quickly solidifies into little lead balls and a flat piece of lead.) The new shapes are compared with the shape of the unheated piece of lead.

6. Glass tubing is rotated in the flame of an alcohol lamp until the glass (solid) softens to a liquid. When the glass tubing is soft, it can be bent or pulled into a fine thread of glass. When it is removed from the heat, it quickly changes back into a solid. The thread of glass can be cut off with scissors to make a tiny nozzle. Other children are cautioned by this group about touching the hot glass. It is *hot and can burn, even when it looks cool*. The children learn how to hold the two ends of the glass tube in their hands and how to roll it with their fingers while heating the center of the tube in the flame.
7. New candles are made from the melted ends of old candles. The old candles are placed in a coffee can and melted over *low heat*. Hot wax can be *dangerous. Remove the wax from the heat the minute it is melted and handle it very carefully, when it is poured into molds such as aluminum dishes and small cans.*
8. One group shows how to scrape about a teaspoonful of wax chips from a candle and how to put them in an empty coffee can. They tell the observers that these chips are *solids*. The wax chips are heated over low heat. What happens? (The chips melt into *liquid* wax.) The can is removed from the stove and set on ice cubes. What happens? (The melted wax solidifies.) These children are allowed to reheat the wax in this can *until it is hot enough to vaporize*. It is safe for them to try this because there is so very little wax in a very large container. Where does the hot wax go? (It changes into a gas, leaves the can as a gas and mixes with the air.)
9. Melted (liquid) wax is observed around the wick at the top of a lighted candle (solid). Attention also is called to the flame. These questions are asked by the work group and answered by the observers—the remainder of the class. Which is yellow, the inside or outside of the flame? (The outside of the flame is yellow.) Why is the inside of the flame not yellow? (The inside of the flame is dark. There is no burning in the center.) Which part of the flame do you think is the hottest? (The area surrounding the dark center, because it is burning.) Do you think the center of the flame is a solid, a liquid, or a gas? (It probably is a gas.) What would cause the liquid wax to change into a gas? (The heat of the flame.) How can we find out whether or not the center of the flame is composed of a gas? The following experiment is tried to help decide whether liquid wax changes to a gas before it burns.

   Two candles and an eight-inch, square piece of window screen are used. One candle is lighted. The screen is held horizontally above the flame and lowered until it pushes down through the center of the flame. When the screen is low enough, the children look down through the center of the screen. They see something that looks like a hole in the middle of the flame. The screen must not be pushed down so far that it extinguishes the flame. These are the questions the work group asks and the answers they receive from the class. Is the flame above or below the screen? (Below) What is above the screen? (We think a gas is above the screen.) This hypothesis is tested by using a lighted toothpick. The lighted toothpick is held at the side and a little above the screen where gas is suspected to be. Some of the gas comes from the candle through the screen. Gas is now above the screen. It is ignited by the burning toothpick. This is tried a number of times for the children to see it happen again and again. The same screen is finally held over the unlighted candle. The same area over the screen is tested in the same way for gas. This time no gas was ignited by the flame on the toothpick. This experience helps the children understand that a gas passes through the screen which is held in the flame. This gas they believe must come from the candle flame because they discover there is no such gas above a screen held over an unlighted candle. Why is the flame above the screen directly over the dark center of the lower flame? (The dark center of the candle flame is composed of unburned gas. The unburned gas comes up through the screen and the heat from the burning toothpick ignites it.) The children now have had enough experience to understand and to discuss why hot candle wax can be dangerous. (When wax is overheated, it becomes a gas vapor and will ignite.)

In class discussions the pupils learn that when a substance changes to a gas, it is said to *vaporize*. Vaporized substances are called *volatile substances*. Many substances vaporize at normal temperatures. Those which do so are even more volatile than wax; and *if they also are combustible*, they should be handled with extreme care. During this discussion the children learn why gasoline, which is a liquid, is commonly called *gas*. They know that people say things like: "I must stop at the gas station to buy gas for my car. My motor burns too much gasoline." The preceding sentences are written on the chalkboard and corrected to read: "I must stop at the gasoline station to buy gasoline for my car. My motor burns too much gas."

During this inquiry the pupils learn why the liquids discussed in the following eight understandings are dangerous. The liquids are very volatile and vaporize at room temperature. They are also combustible.

1. It is dangerous to clean clothes with gasoline.
2. Scrubbing clothes with gasoline or rubbing them with gasoline can cause an explosion.
3. Gasoline should be kept in covered containers.
4. A lighted cigarette or spark held above an open pail of gasoline can cause an explosion.
5. Paint thinner and turpentine should be stored in covered containers.
6. Paint, mixed with thinner or turpentine, should be stored in covered containers.
7. Wiping cloths used by painters should be destroyed.
8. No building will pass a fire inspection test, if volatile substances which are combustible are in uncovered containers or on discarded wiping cloths.

In their own vocabulary, pupils should state their scientific findings. These are some pupil statements of understandings: Heat causes solids to change into liquids and liquids to change into gases. Cooling causes gases to change into liquids and liquids to change into solids. The above statements are improved by qualifications to read: With heat *some* solids change into liquids and *some* liquids change into gases. It is possible to change *some* gases into liquids and *some* liquids into solids by cooling them. Many substances can be changed by either cooling or heating. The changes observed are *physical changes* because only the physical forms of the substances (solid, liquid, gas) are changed. Discuss with the class why general statements need to be qualified and why scientists are always careful to qualify their statements. Let the pupils discuss how this practice of qualifying statements is a way of saying that there may be more information which they have not learned. To a scientist, it may be a way of saying that there may be more facts to be discovered. Help the pupils to understand that one of the basic qualities of scientists is open-mindedness.

When some pupils ask questions like those that follow, it is evident that there is more to be learned and that they want to explore further into this problem of change in form. Encourage these interested pupils to try to find answers to such questions. Will all solids change to liquids? Can solid metals, such as iron, gold, silver, and aluminum, be changed to liquids? Can any of them be changed? Why is it harder to change solid iron to liquid iron than it is to change solid aluminum to liquid aluminum? Why are some liquids more volatile than others? How is liquid oxygen made? How is solid carbon dioxide (dry ice) made? Why does dry ice change from a solid to a gas?

3. If enough heat to change solids, such as iron or copper, into liquids is not available, what other changes can be observed?

The critical and imaginative thinking of pupils devised some of the following experiences. What experiences can other pupils devise? Provide time and encouragement for pupils to try their own skills in problem solving on this inquiry. They may wish to try experiments like the ones here or they may devise quite different and original ones to try. Encourage personal and group involvement in the inquiry.

1. A piece of bare copper wire is stretched between the backs of two chairs. From this horizontal wire is hung another wire with a weight on the end of it. The weight almost, but not quite, touches the floor. The horizontal wire is heated with an alcohol lamp. If a candle is used to heat the wire be sure the floor is protected from the candle drippings. What happens? (The weight touches the floor.) When the heat is removed, what happens to the weight? The experiment should be repeated several times. A prediction is made about what will happen, if the wire is cooled with an ice cube. The prediction is tested. This related

question is explored. Why would linemen, who string wires between utility poles, need to know whether or not heat and cold affect wires?

2. A piece of equipment called a *ball and ring* is borrowed from the science supply room. It is determined that the solid metal ball will just pass through the solid metal ring. After the ball is heated, it will not pass through the ring. What happens when the ball is cooled? (It again will go through the ring.) What happens to the solid metal ball when it is heated and when it is cooled? (It expands when it is heated and contracts when it is cooled.)
3. A piece of equipment called a *compound bar* is also borrowed from the science supply room. A compound bar is a flat metal bar made of two different metal layers. The middle of the bar is heated in the flame of an alcohol lamp. What happens? (The bar curves.) Sometimes it seems to curve downward and at other times upward. (The pupils discover that *this only seems to be true* depending on how the bar is held.) It is observed that each side of the bar is made of a different metal and that the heated bar always curves in the same direction in reference to the two metals. What happens when the bar cools? (The curve disappears.) What happens to these two metals when they are heated? (They both expand.) Why does the bar curve? (One metal expands more than the other metal.)
4. A red and green paper model is invented to help explain how the greater expansion of one metal causes the bar to curve. The red paper strip is cut one and a half inches longer than a green paper strip of the same width. When the two ends of these two paper strips are stapled together, what happens? (The paper model curves.)

There are other experiments which can demonstrate how solids expand when they are heated and contract when they are cooled. Encourage the pupils to locate or invent ways to further demonstrate this principle.

Here are some applied problems for discussion. Why is a glass jar with a screw cap held under hot water to help unscrew the cover? Why are the rails on railroad tracks usually laid with a space between the ends of the rails? Why are there metal plates with space between them running at intervals across the paving of bridges? If an automobile engine becomes overheated either from lack of oil or water, why do the pistons sometimes stick in the cylinders?

4. What causes liquids to expand and contract?

Teachers can set the classroom tempo in a way which will motivate students to solve this problem. Allow students freedom of inquiry, but at the time, employ all safety precautions whenever heat, flame and combustible substances are involved. Within this framework, pupils can discover, plan, and try experiments similar to the ones here. The materials described in this inquiry should be in the science supply rooms of elementary schools.

1. A Pyrex flask is filled to the top with water dyed with red ink. A long piece of glass tubing is fitted into a one-hole rubber stopper. The stopper is fitted into the neck of the flask. The red water probably will rise a little way into the tubing at this time. Mark the height of the colored water in the tube. Warm the water inside the flask by clasping hands around the flask. What does the water do? (It rises in the tube.) Put another marker on the tube to mark this new height. Apply more heat to the flask by setting it in a pan of hot water and finally by setting it on a stove. What is discovered? (Water expands when it is heated. If it is free to do so, it will occupy more space. As the water in the flask expands, it pushes up into the space inside the glass tubing.) What happens when the water in the flask is cooled? (Water contracts when it is cooled. It occupies less space. It moves down the tube into the flask again.)
2. Empty the flask and fill it exactly the same way with rubbing alcohol colored with red ink. Heat it very slowly and observe the changes which occur. Do not let the alcohol overflow or spill on a hot stove because it could cause a fire.
3. Use a test tube with a one-hole stopper to fit it, a long piece of glass tubing, and a test tube holder. Fill the test tube with mercury (liquid) and fit the stopper and tube into the test tube. Heat the tube of mercury. Observe what happens as it is heated and also as it cools. (The mercury expands and contracts.)

Children should now be able to apply their understandings of the expansion and contraction of water, alcohol, and mercury to thermometers. What happens when thermometers are heated and cooled? Locate a metal thermometer and see what happens when it is heated and cooled.

These thermometers use the principle of expansion and contraction of liquids and solids to record temperature changes. The metal thermometers have a round dial with a movable pointer which indicates the temperature.

5. What causes gases to expand and contract?

Pupils can plan experiences similar to the ones in this inquiry. If given opportunities and freedom to improvise, pupils will demonstrate many variations and original experiments.

1. Empty and thoroughly dry the Pyrex flask. Fit the one-hole stopper with the glass tubing into the flask. The flask is now full of air, which is a mixture of gases. Put some colored water in a glass quart jar. Turn the flask and tube upside down and place the end of the tube into the colored water in the jar. Heat the flask with the hands. What happens to the air when it is heated? Apply more heat to the flask by placing it in the sunshine and by holding an alcohol lamp near it. Let the flask cool to room temperature. Lower the temperature further by rubbing the flask with ice cubes. What happens to the air when it is cooled? Try reheating and recooling the flask of air several times. Make certain that the end of the tube is not removed from the jar of colored water until the pupils are completely finished with the experiment.
2. Remove the stopper and tubing from the flask and stretch a toy balloon over the neck of the Pyrex flask filled with air. Heat the flask. What does the air do as it is heated? Where does some of the air go? (Into the balloon.) Remove the flask from the heat and let it cool. What happens to the balloon? Where does the air which was inside the balloon go when it contracts? (Back into the flask.) Repeat until the experiment is understood.
3. Try a variation of the preceding experiment. When hot air expands into the balloon, pull the neck of the balloon away from the flask in order to let the air in the balloon escape into the room. The balloon will hang down on the outside of the flask. Continue heating the flask until the balloon "pops up" again. Release the air once more. Do this six or seven times. Now remove the flask with the balloon on it from the heat. Watch it while it cools. If the balloon is well centered on the neck of the flask, it should turn inside out and go down into the flask. What happens to the air that remains in the flask when it is cooled? (It does not fill the flask, because much of the air from the flask has been allowed to escape into the room.) Why did the balloon go into the flask? (The air in the room pushes the balloon into the space left vacant by the air that has escaped.) The flask should be reheated and recooled several times until what happens and why it happens is thoroughly understood.
4. Bring small round balloons and glass jars like "Skippy" peanut butter jars from home. Blow up the balloons so that they just fit inside the jars, but so that they can be pulled out of the jars with a little tug on the necks of the balloons. Tie the necks of the balloons to keep the air inside. Have two big pans of water ready to use. One pan should be nearly full of very hot water and the other of ice water. Hold the jars, with the balloons in them, in the hot water, allowing the hot water to come up on the outside of the jars, but being careful not to allow any hot water to go inside the jars. Now pull upward on the necks of the balloons. What happens? (The balloons fit so tightly inside the jars that the *jars* can be lifted by pulling on the balloons.) What causes the air inside the balloons to expand? (The heat released by the hot water.) Cool the jars, with the balloons inside them, in ice water. Why is it easier to remove the balloons from inside the jars? (The air and the balloons have contracted.) The air contracted when it cooled and this caused the balloons to contract too.

Discuss the air expansion in automobile tires. Why do people sometimes let air out of their automobile tires when the temperature is very hot in summer?

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. There are three kinds of material: solids, liquids, and gases. Solids have a shape of their own and tend to keep their own shape. Liquids have no

shape of their own but they will take the shape of a container and tend to keep the container's shape. A gas has no shape of its own and does not tend to keep the shape of an open container.

2. Many solids can be changed into liquids and many liquids into gases. Gases can be changed into liquids and liquids into solids. These changes are called *physical changes* because only the physical form (solid, liquid, gas) of the substance is changed. We caused changes like these by heating and cooling substances.

3. We observed that some solids expanded when they were heated and contracted when they were cooled.

4–5. We observed that some liquids and gases expanded when they were heated and contracted when they were cooled. There are other ways to cause these physical changes.

Chapter Ten

Molecules and Atoms: Compounds and Elements

INQUIRIES

1. How do scientists use the molecular theory to explain changes that occur when solids, liquids, and gases are heated?

2. What are some of the experiments which can be used to substantiate the molecular theory?

3. Why are some molecules larger than others? What is inside most molecules? What is smaller than most molecules?

4. How many kinds of atoms are there? How many kinds of molecules are there?

5. What is a chemical change? How does it differ from a physical change?

6. How common are chemical changes? What are some of the chemical changes that are occurring all around us?

7. How important are chemical changes? How can they be controlled?

1. How do scientists use the molecular theory to explain changes that occur when solids, liquids, and gases are heated?

In the preceding chapter, the children have made observations about different kinds of solids, liquids, and gases. Even with the limited amount of heat that they could use in their experiments, they were able to observe that some substances change from a solid to a liquid form, and some from a liquid to a gaseous state. They saw that cooling some substances caused them to change from a gaseous state to a liquid state and from a liquid to a solid form. They should know that many other substances also change their *form* when they are heated and cooled sufficiently. They have also seen that some solids, liquids, and gases *expand* when they are heated and *contract* when they are cooled.

Review these observations with the children until you are certain that they understand that these phenomena are characteristic of many solids, liquids, and gases. The purpose of this review discussion is to stimulate the group to a point where some children will begin to ask questions like these: "*Why* do they do this? What makes them do this?"

Now challenge the children to try to explain these phenomena in their own way. Ask them what they think causes these things to happen. Tell them that scientists were puzzled by these same things for many years and that they made scientific guesses called *hypotheses* to try to explain what was happening. After they had made the hypotheses, the scientists tried to prove or disprove them by checking all known sources of information and by making new observations. Ask each pupil to form his own hypothesis to explain the phenomena of changes that occur to solids, liquids, and gases. Caution the class that their hypotheses must fit all the facts known *to them* as well as all of *their* observations. Discuss each pupil's hypothesis. Write on the chalkboard the hypotheses that the class regards as having merit.

This kind of experience provides opportunity for the children to identify themselves with the kinds of problems that scientists face. Ask the children not to look in books for ideas for a hypothesis, because scientists don't find their ideas in books when they are developing a theory. The children should be aware of one advantage they have that scientists did not have in developing their hypotheses into the *molecular theory.* The scientists were only beginning to form concepts about the structure of substances. The word *molecule* was not commonly used as it is today and the concept of a molecule was not yet entirely clear to them. Today, the word *molecule* is a part of the vocabularies of many children. They have developed some concepts of what molecules are, and they can include these concepts in the theories which they formulate.

After the children have formed and recorded a theory of their own, ask them to read about molecules and the molecular theory in their science books. Have them report to the class the things that they learned from these books. Let them make a chart for the bulletin board called: "*What Scientists Say about Molecules.*" Under this title have the children list their findings. They should be able to find information like this:

1. A molecule is the smallest part of a compound.
2. Molecules are very small. It is difficult even to imagine how small they are. There is much space between the molecules of a substance.
3. The molecules in a substance are always moving unless the temperature of the substance is at absolute zero (−273°C). At absolute zero, the molecules of a substance are believed to be motionless. The molecules in a substance move in all directions. They bump against each other and bound off in other directions.
4. Heating molecules makes them move faster and faster. As the molecules gain speed, they collide more frequently. These collisions usually cause the molecules to bounce farther apart. As the molecules move faster and faster and bounce farther and farther apart, they usually take up more and more space. When the molecules spread out and occupy more space, the substance expands.
5. Cooling usually causes molecules to move more slowly. Slow-moving molecules collide less frequently and usually occupy less space. When molecules move together into less space, the substance contracts.
6. The relative distances between the molecules of a substance and their relative speed usually determine whether the substance is a solid, liquid, or gas.

Finally, ask the pupils *to compare their recorded hypotheses* with the *scientifically acceptable molecular theory.*

2. What are some of the experiments which can be used to substantiate the molecular theory?

If the children thoroughly explored their science books while they were working on the previous inquiry they will be ready with many simple experiments that they can use to substantiate one or more parts of the molecular theory. Allow class time for them to do these experiments, the ones they have seen on television, and *the ones they invent.* They should understand that they are doing the experiments not only for the fun of doing them, but also in order to clarify some part of the theory. Encourage the class to challenge the experimenters with questions like these: "Will you explain what your experiment shows because I didn't quite understand it? Would your experiment work, if you—(did this or that to it)? What part of the theory are you trying to substantiate?"

Let the children know that scientists question themselves and each other in this way because it helps them to clarify their thinking. By the same kind of friendly challenge, the children can stimulate each other to do *critical thinking.*

Have the children locate the statements that their experiments illustrate on the molecular theory chart which they made in the previous inquiry. Each one who can satisfy the class that his experiment substantiates one of the statements on the chart, might put his or her initials after that statement.

When children are encouraged to use their initiative in experiences like this, they have excellent opportunities to *practice the scientific method* and *to develop problem-solving skills and scientific attitudes.*

The children may do the following experiments if they have not already done them as a result of their earlier research.

Mix one level cupful of alcohol with one level cupful of water. When these two compounds are mixed, they will find that they have less than two cupfuls. Try to explain why, in this experiment, one and one doesn't make two. Because the children know that compounds are composed of molecules, they may be able to explain the results of this experiment. If their reasoning is correct, they will say, "There are spaces between the molecules in each of these two compounds. Some of the water molecules move into the spaces between the alcohol molecules and some of the alcohol molecules move into the spaces between the water molecules. When this happens, there will be less than two cupfuls." Check their understanding of the results of this experiment, by having them draw a picture showing what happens to molecules when these two substances are mixed. A different color of crayon might be used to make the two different kinds of molecules. Remind the children, while they are planning their picture, that the molecules of each kind of liquid must be the same distance apart before and after they are mixed. Perhaps the class would like to experiment with other kinds of liquid compounds to see whether they can obtain results similar to the one they obtained by mixing alcohol and water.

This experiment will help the children understand why scientists believe that the molecules of different substances are continuously moving. Place a drop of ink on the surface of some water in a glass tumbler. Be very careful to avoid jarring the table while observing the experiment. The ink molecules will slowly diffuse or mix with the water. Try to explain what may cause this diffusion. The molecules of ink and water are moving around in the tumbler. The ink molecules are believed to be diffused by the random motion of the water molecules which collide with them. Have them test their explanation by placing a drop of ink in a tumbler of cold water and another drop of ink in a tumbler of hot water. Encourage the children to *predict* the results of this experiment by asking them this question: "If diffusion is caused by the motion of molecules, in which tumbler will diffusion occur more rapidly?" (The ink will diffuse more rapidly in the tumbler containing hot water because the molecules will be moving faster.) Have some of the children read about Robert Brown who, in 1827, observed the random motion of tiny particles in a liquid. Not until the beginning of the 20th century was the cause of this phenomenon explained on the basis of molecular collisions and referred to as the *Brownian movement.*

What makes scientists believe that, even though the temperature of different substances may be the same, the molecules in these substances may not be moving with the same speed? This experiment will help the children answer this question. Have them check the temperature of the following liquids to make sure that they are at room temperature before doing the experiment: alcohol, ammonia, cleaning fluid, toilet water, and water. Place one level teaspoonful of each of the liquids in separate containers. Plastic food containers make good dishes for this experiment. Place the dishes with the liquids in them on the table where the children can observe the results. As soon as the stoppers are removed from the bottles, the children will begin to smell the different odors. Ask the class what must be happening to some of the molecules in the liquid, since they can smell them in the air. The liquids are changing into vapor and evaporating. In order to evaporate, the molecules that vaporize must be pushing into the spaces between the air molecules above them. If this is true, then it seems likely that liquids that evaporate more rapidly may be composed of molecules moving at high speed. Which liquid evaporated the fastest? (Cleaning fluid.) Which liquid evaporated the slowest? (Water.) In which liquid are the molecules likely to be moving more rapidly? (In the cleaning fluid.)

This experiment will help the children to understand the relationship between vaporization and air pressure. Fill a flask about one-third full of water. Question the group to make sure they visualize the moving air molecules pushing down on the water (air pressure) and the moving water molecules pushing up on the air. *Molecular energy* is caused by the movement and weight (mass) of molecules. Call their attention to the fact that when water evaporates, some of the water molecules are continually bouncing into the air above the surface of the water. Help them to understand that this molecular movement also causes the air molecules to mix with the water.

Now have one of the children put the flask over a source of heat. While the water is heating, ask them questions like these: What do you think is happening to the speed of the air and water molecules? (Heat makes them move faster.) What do you predict about the space these molecules will need when they are heated? (Both will collide more frequently and bounce farther apart. Both the air and water molecules will need more space. Some of the air and water molecules should leave the flask.) What evidences can you see that indicate that the water molecules are changing places? (Vapor bubbles in the water rise nearly to the surface and burst. Moisture collects on the inside of the flask above the surface of the water. Condensed water vapor can be seen leaving the flask.) What evidence is there that the water molecules have increased their energy? (There is more evaporation than there was before the water was heated.)

Remove the flask from the heat and stopper it tightly. In an instant, the water stops boiling because cooling starts to take place. When this happens, place a cold, wet paper towel around the upper part of the flask. The children will be surprised to see the water begin to boil again. Let them try to explain this phenomenon. Why does the wet towel cause this to happen? (It removes heat from the flask and from the steam above the water. Some of the steam condenses. This reduces the pressure on the water's surface. As the pressure on the surface of the water becomes less, the molecules in the water need less energy to become active again. The water boils.) Continue cooling the flask by wetting the towel again and again in cold water. The children will observe the water boil again and again. Each time that the flask is cooled, visualize the change that is occurring above the surface of the water. As more and more steam condenses, the pressure on the water becomes less and less.

The different temperatures at which the water boils in the flask can be recorded by inserting a thermometer into a one-hole rubber stopper and using this stopper in the flask. Heat the flask again until the water boils hard. Stopper it tightly, shake vigorously, and record the temperature at which the water boils each time the flask is cooled with a wet paper towel. This is convincing evidence that the boiling point of water depends on the pressure exerted on the surface of the water.

Look up the description for the boiling point of water and explain why books always say, "The boiling point of water is 212° Fahrenheit, at sea level." The class should also check the boiling point of water in the schoolroom. If the school happens to be located above sea level, the boiling point of water will be less than 212°F. If they could go into a mine to a depth lower than sea level, the boiling point of water would be above 212°F. Ask them to explain why it takes approximately eight and a half minutes to cook a "three-minute" boiled egg on Pike's Peak which is 14,000 feet above sea level. (The air pressure is less at high altitudes. Water boils at such low temperatures at high elevations that it takes food a longer time to cook.)

In an open kettle or a kettle with a loosely fitted lid, water never reaches a temperature higher than its boiling point. Boil water in an open container. Turn the heat to "high" and check the temperature at which the water is boiling. Turn the heat to "medium." Wait about two minutes and check the temperature of the boiling water. Turn the heat to "low" and, if the water continues to boil, check its temperature again. The temperature of the water remains the same as long as it continues to boil. Can this information be used to lower the amount of gas or electric bills? (Yes.) Pressure cookers are used to raise the temperature at which water boils. Because the steam cannot freely escape from the pressure cooker, it increases the pressure on the surface of the water and the molecules in the water need more heat energy to change into steam. Therefore, the temperature at which food cooks in a pressure cooker is higher than boiling temperature.

Discuss the effect of the changes in pressures on gases, liquids, and solids. Ask the class to investigate problems like these:

1. What would happen to a gas if it were put under very high pressure? (The temperature of the substance would rise and it would change to either a liquid or a solid depending upon the amount of pressure.)
2. How is the liquid oxygen that is used in rockets made? (It is made by subjecting oxygen gas to a very high pressure.)
3. How is dry ice made? (It is made by compressing carbon dioxide gas.)
4. Why does the barrel of a bicycle pump get hot when it compresses air into a tire? (There are two reasons: (*a*) Heat is produced by the *friction* between the piston and the inside of the cylinder and between the piston and the air molecules that are being compressed. (*b*) The *compression*, or squeezing, of the air molecules in the cylinder and in the tire also produces heat.)
5. Why do air compressors in gasoline filling stations get so hot when they are compressing air? (For the same reason that the barrel, or cylinder, in the bicycle pump gets hot.)
6. How does a compression-type electric refrigerator cool the food and water inside the refrigerator box? (A refrigerant, called *freon*, circulates through the coils of the refrigerator. This refrigerant is compressed into a liquid by an electric pump. When the liquid refrigerant moves through the coils near the food and water, it absorbs heat from these substances. The heat from the food causes the liquid freon to expand into a gas. This gas circulates back through the cylinder of the pump where it is compressed into a liquid. The liquid is forced through the coils again to absorb more heat. This change from a liquid to a gas, and back again, occurs over and over.)
7. How does the refrigerant get rid of, or release, the heat which it absorbs from the inside of the refrigerator box? (When the pump compresses the refrigerant into a liquid, it gives up the heat, which is absorbed from the food, to the compressor pump. The heat from the pump heats the air around it. In the electric refrigerator there is a fan that circulates air around the compression pump. The fan blows away the hot air, and cooler air from the room replaces it.)
8. What other devices do some people have in their homes that operate like a refrigerator? (Air conditioners. A fan in the air conditioner draws the hot air of the room over coils containing a refrigerant. The refrigerant removes some of the heat from the air and circulates the cooled air back into the room. The heat is expelled from the refrigerant to the pump, to the air, and finally to the outdoors.)
9. What will happen to the rate of evaporation of a liquid if the air pressure above it is reduced? (The liquid will evaporate more rapidly. See p. 116 for an experiment showing that water will boil at a lower temperature if the pressure above it is reduced.)
10. How are evaporated and powdered milk made from whole milk? (The liquid is heated, and the pressure above it is reduced so that vaporization occurs rapidly.)
11. How is concentrated orange juice made? (The same process is used as in making evaporated and powdered milk.)

Discuss the fact that some of the larger molecules of certain substances have been photographed with the electron microscope. Have the children look for information about this kind of microscope and report their findings to the class. They may be able to find a picture of a molecule taken by such a microscope. If there is an electron microscope in your community, try to make arrangements for your class to see it and to talk with the operator.

3. Why are some molecules larger than others? What is inside most molecules? What is smaller than most molecules?

Write on the chalkboard a list of common molecules like this:

Can you find names for these molecules?

1. H_2O __________
2. CO_2 __________
3. NaCl __________
4. CO __________
5. H_2O_2 __________
6. H_2SO_4 __________
7. HCl __________
8. $C_{12}H_{22}O_{11}$ __________
9. O_2 __________

(*Answers*: 1. water; 2. carbon dioxide; 3. table salt; 4. carbon monoxide; 5. hydrogen peroxide; 6. sulfuric acid; 7. hydrochloric acid; 8. sugar; 9. oxygen.) Try to find other molecules to add to this list.

Give the children time to consult books and to question people about this list of molecules. But set a time limit for checking their findings. Prepare a place in the room where the children can make a list of "Mystery Molecules." Here they can record the formulas for other molecules which they may discover while they are searching for the names of the molecules in the original list of nine. Make it a rule that the children must have the name of the molecule, as well as its formula, before they can write the formula on the mystery list. When a child thinks he has found the name of one of the molecules, he should check it with the person who supplied the formula. If he is correct, he may write the name beside the formula.

The formulas should help the children realize that the molecules of substances contain two or more atoms. It should also help them to understand that some molecules contain two atoms of the same kind and that many, many molecules contain more than one kind of atom. Discuss with the children the symbols and numbers used in the formulas. Help the children to understand that a capital letter (C), or a capital letter followed by a small letter (Cl) are symbols representing the kind of atom in the molecule. Also help them to understand that a number, a little below the line (H_2O) belongs to the symbol for the preceding atom and indicates the number of this kind of atom in the molecule. If there is no number after the symbol, it means that only one atom of that particular element is present.

Make a chart, similar to Table 10.1, to help clarify the meaning of the symbols used for the atoms and the quantity of each kind of atom in the molecule.

Children can develop understanding of molecular structure by building models of molecules in a way similar to that used by scientists. Even if the children do not get the positions of the atoms exactly right within the molecule, a model will help them to develop the concept that most molecules are composed of two or more atoms and that molecules are usually larger than atoms. It will also help them to understand why some molecules are larger than others.

Two-dimensional models can be made with circles cut from paper of different colors. Arrange the circles so that they touch each other and pin them flat to the bulletin board. Use a separate color to represent each kind of atom. These models make interesting bulletin board materials.

Three-dimensional models can also be made with marbles or beads. Again, use a different color, and the correct number of beads or marbles, for each kind of atom. Tie these marble or bead molecules in transparent plastic wrap and tack them on the bulletin board. If beads are being used to represent the atoms in a molecule, they can be held together with thread and displayed in the same way as the marbles.

4. How many kinds of atoms are there? How many kinds of molecules are there?

In the preceding inquiry, the children learned that chemists write the formula of a molecule by using *symbols* for the atoms that it contains. In the molecules listed in Table 10.1, there were six different kinds of atoms. If the children added other kinds of molecules to the list, they may know names and symbols for more than seven different kinds of atoms. If the children examine many science books, they may find lists that contain anywhere from 92 to more than 100 kinds of atoms. In order to understand why all books do not list the same number of atoms, or elements, the class should compare the publication dates of the books they used. Scientists have

Table 10.1

FORMULAS AND SYMBOLS

Formula for Molecule	Name of Molecule	Symbol and Name of Atoms in the Molecule	Number of Each Kind of Atom in the Molecule
H_2O	Water	H (hydrogen) O (oxygen)	$H + H + O$
CO_2	Carbon dioxide	C (carbon) O (oxygen)	$C + O + O$
NaCl	Salt	Na (sodium) Cl (chlorine)	$Na + Cl$
CO	Carbon monoxide	C (carbon) O (oxygen)	$C + O$
H_2O_2	Hydrogen peroxide	H (hydrogen) O (oxygen)	$H + H + O + O$
H_2SO_4	Sulfuric acid	H (hydrogen) S (sulfur) O (oxygen)	$H + H + S + O + O + O + O$
HCl	Hydrochloric acid	H (hydrogen) Cl (chlorine)	$H + Cl$
O_2	Oxygen	O (oxygen)	$O + O$
$C_{12}H_{22}O_{11}$	Sugar	C (carbon) H (hydrogen) O (oxygen)	$C + C + C + C + C + C + C + C + C + C + C + C + H + H + H + H + H + H + H + H + H + H + H + H + H + H + H + H + H + H + H + H + H + H + O + O + O + O + O + O + O + O + O + O + O$

learned about a number of new elements during the past 25 years.

For class reference, the children should construct a basic chart on which they can write the kind of element, or atom, its symbol, and its atomic number and weight.

Organize this chart like Table 11.2 and write the atomic numbers 1 to —. As the children learn something about the atom of an element, they can list its name, symbol, and weight after its atomic number. They might start this chart by finding the atomic number and weight for the six atoms they studied in Table 10.1 and then add any others with which they are acquainted. Some children are certain to know some of the elements that have been discovered recently. Encourage the children to read about these "new" atoms. Perhaps they can find out when they were discovered and for whom or what they were named. As the children add more and more names to their chart of the elements, they acquire a "working vocabulary," which includes the names of many elements. This vocabulary may vary from year to year and from community to community. For example, only a few years ago no child, and very few adults, would have heard about the element uranium. Today, that element's name is in almost everyone's vocabulary.

Have the children collect objects containing as many of the different kinds of atoms as possible and display their collection on a table or a bulletin board.

Molecules that contain two or more different kinds of atoms are called *compounds.* Hundreds of thousands of different kinds of compounds can be made by combining the 100 or more atoms in different ways. It may help the children to appreciate the many thousands of possibilities that exist for making compounds from different combinations of atoms if they compare these possibilities with those in word formation in which only the 26 letters in our alphabet are used. Over half a million English words have been made by combining these 26 letters in different ways. There are at least four times as many known elements as there are letters in the alphabet and many more than four times as many possibilities for making different combinations. This discussion about compounds provides an excellent opportunity for children to talk about some of the new substances that chemists have produced within the past few years. A very colorful and interesting display can be made by having the children collect such materials as acrilan, dacron, nylon, plastic wrap and various plastic materials.

5. What is a chemical change? How does it differ from a physical change?

Review Inquiry 3 in Chap. 9 for experiences that show physical changes. In these experiences, the substances change their physical form (solid, liquid, or gas). Review the physical changes of water. Even though water changes its physical form from a solid (ice), to a liquid, and to a gas (water vapor), it always has the same chemical formula (H_2O). Be sure that the children understand that these changes are called *physical changes* because only the physical form is changed. No new chemical substance is formed.

Ask the children to explain how a *chemical change* differs from a physical change. Encourage them to express their personal opinions. Direct their thinking with questions like these: If a physical change results in the physical form being changed, what occurs in a chemical change? (The chemical form, or structure, will change.) How do chemists express the chemical structure of a substance? (All compounds and elements are composed of atoms. Each substance has a different chemical formula. The formula shows the number and kind of atoms in the molecule.) Why are different elements or compounds formed during a chemical change? (Because the structure or chemical form of the molecule is changed.) Why should the *loss* of one or more atoms cause a chemical change? (Because the structure, or formula, is changed.) Why should a molecule change into a different molecule if it gained one or more atoms? (The formula is changed.) Why should a chemical change occur if a molecule exchanged atoms with another molecule? (The formula is changed.)

Ask the children what might happen if the atoms in water molecules were separated. (The water would change into different substances. The children might be able to guess that it would change into the elements, hydrogen and oxygen.) How would the new molecules, that are formed, differ from the water molecule? (The hydrogen molecule will lack an oxygen atom and the oxygen molecule will lack two hydrogen atoms.)

Ask the children to look in their science resource materials for an experiment they can do that will prove that water can be broken down into hydrogen and oxygen. They should be able to locate an experiment called *electrolysis* of water. Write the word on the blackboard so they can use the index in their books to find the experiment. They need the following equipment and supplies for doing this experiment: the electrolysis equipment, dry cells, or a power supply unit (rectifier transformer), which can be substituted for batteries, bell wire, a glass stirring rod, a magnetic compass, and a bottle of sulfuric acid (see Fig. 10.1).

Connect one piece of wire from one binding post of the dry cells to one of the binding posts on the support of the electrolysis equipment. Connect a second wire from the second post of the dry cells to the second post on the support of the electrolysis equipment. Call the children's attention to the open space between the two platinum electrodes in the electrical circuit. (See Chap. 19, Inquiry 2.) Test the circuit with a magnetic compass to find out whether a current is flowing through the wires. Hang the electrolysis support on one edge of the glass jar. The glass jar is a part of the electrolysis equipment. Fill the jar about three-fourths full of water. While the children are assembling the equipment, have them tell you again about the structure of the water molecule. (The water molecule is composed of two hydrogen atoms and one oxygen atom. Its formula is H_2O.) The children will have a better understanding of why energy is used to break down the water molecules if they know that

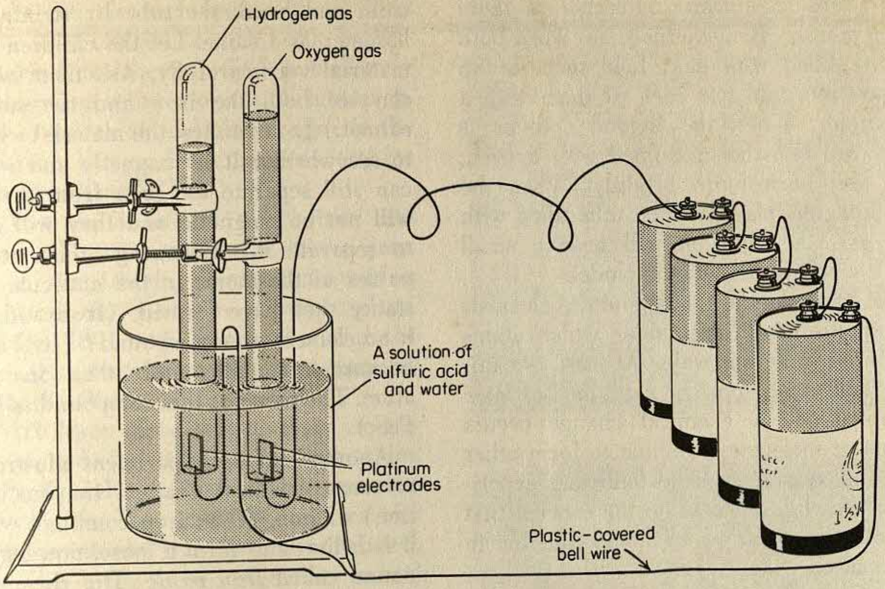

Hydrogen gas
Oxygen gas
A solution of sulfuric acid and water
Platinum electrodes
Plastic-covered bell wire
1½V

Fig. 10.1 Electrolysis of water.

chemists believe that the atoms in the molecules of substances are held together by electrical attraction. The electricity flowing through the circuit in their experiment must provide enough energy to overcome this attraction between the hydrogen and oxygen atoms in the water molecule.

Draw the children's attention to the platinum electrodes that are surrounded by water. It may seem to them that the water completes the circuit between these two electrodes. Ask the children whether they can see any evidence that the electricity is flowing through the water from one electrode to the other. Have them hold the magnetic compass under one of the wires in the circuit to test for the flow of electricity. The compass needle will be deflected from its north-south position if an electrical current is flowing through the circuit. Even though the compass does not register a flow of electricity, it does not mean that there is no current. The children should be careful to qualify their statements about the result of this test. Statements such as these would be acceptable: "The magnetic compass, so far as we could see, did not register a flow of electricity, but the current might be so weak that the compass would not detect it." (If tap water is used in this experiment, a very weak current of electricity will flow through the water between the two electrodes. Tap water, or water that has not been distilled, is a poor conductor of electricity, but it is a better conductor than distilled water.)

Fill the two test tubes, which are a part of the electrolysis equipment, with water, cover the open end of the tubes, invert the tubes, and place the covered end of the inverted tubes under the water in the jar. Remove the covers from the open ends of the test tubes and place an inverted tube over each of the platinum electrodes. Use the spring clips on the electrolysis support for holding the tubes over the electrodes. Add a few drops of sulfuric acid (H_2SO_4) to the water and thoroughly mix the acid in the water by stirring with a glass rod. The sulfuric acid added to the water makes the water a better conductor of electricity. Test for a flow of electricity with the compass. Watch for bubbles collecting on the two electrodes. Keep adding a little sulfuric acid (H_2SO_4) to the water until gas bubbles begin to collect very rapidly around the electrodes. These gas bubbles will gradually collect at the top of the test tubes and displace the water in the tubes. One test tube will fill twice as rapidly as the other. Ask the children to guess why this happens. (There are twice as many hydrogen atoms in a water molecule as there are oxygen atoms.) Remove the tubes when both of them are filled with gas; hold them in an inverted position, and test each of them with a lighted splinter. When the lighted splinter is pushed upward into the tube filled with oxygen, the flame will burn more brightly. When the burning splinter is placed in the tube filled with hydrogen gas, the children will hear a small "putt-like" sound as the gas explodes.

In order to make new compounds, chemists must set up the conditions under which atoms will combine in different ways. At least two different kinds of atoms must be combined to form a new compound. A chemical change occurs when atoms or molecules combine to form other molecules and vice versa. The following experiments will help children develop the concept that chemical changes occur when atoms combine to form molecules.

For the first experiment, the children need powdered iron (iron filings), sulfur, a magnet, a test tube, a test tube holder, a stirring rod, and a source of heat. Have them test both the iron powder and the sulfur to find out whether they are magnetic. (The iron powder will be magnetic; the sulfur will not be magnetic. See Chap. 17.)

Borrow a platform balance and have the children weigh 4 grams of sulfur and 7 grams of iron powder for the next part of this experiment. Place a piece of filter paper on the scales. Adjust the scale so that it balances. Move the indicator on the beam of the balance to the number of grams to be weighed. Scoop a small amount of the substance from the container and place it on the filter paper. A tongue depressor or a small spatula can be used for a scoop. Continue adding more and more of the substance until the scale is again in balance. Have one child mix together the 4 grams of sulfur and 7 grams of iron on one piece of filter paper. Test this mixture with the magnet. (The iron will be magnetic. Some of the sulfur powder will cling to the iron and the magnet, even though it is not magnetic.) Notice that the magnet separates most of the iron from the sulfur. Place this mixture in a test tube and heat it over a hot flame. When the contents of the tube have cooled, remove it from the test tube. If the material does not come out of the tube easily, it may be necessary to cover the tube with a cloth and break the tube by striking it with a hammer or a stone. Let the children observe the material very carefully. Ask them whether they can see both the iron and the sulfur. (They cannot.) Let them test the material with a magnet to see whether it is magnetic and whether they can still separate the iron from the sulfur. (It will not be magnetic and they will not be able to separate it.) Encourage them to guess the names of the atoms in the molecule of the substance they have formed. (Iron and sulfur.) Is it an element or a compound? (It is a compound because it contains more than one kind of an atom. The name of this compound is iron sulfide, FeS.)

Another simple experiment illustrates a very common chemical change, the rusting (oxidation) of iron. When iron combines with oxygen, it is believed to form a loose, powdery, red compound called *iron oxide*. The chemical formula for this oxide is not given because scientists are not certain as to how the atoms of iron, oxygen, and hydrogen are combined to form a molecule of rust. However, the children can experiment with a variety of materials made of iron, such as iron powder, carpet tacks, some kinds of paper clips, and steel wool.

At the beginning of the experiment, test these materials to determine whether or not they are magnetic. Because rusting is such a common chemical change, the class may be able to suggest some of the conditions essential for rusting to occur. (The conditions are water, oxygen, and heat.) Plan experiments with controls to test these three conditions.

1. **Water.** Wet the inside of one bottle. Thoroughly dry the inside of another bottle. Sprinkle iron filings in both and cover. Leave the jars for 48 hours. In which jar have the filings rusted? Was water essential for rusting? (Yes.)

2. **Oxygen.** Wet the inside of two bottles. Sprinkle the inside of one with iron filings. Stand both bottles in an inverted position in a pan of water. Observe the water level on the inside of the bottles. (Because both bottles are full of air when the experiment is set up, no water will go inside of either bottle.) Observe the water level inside the bottles again at the end of 48 hours. (The water will have risen inside the bottle where the iron filings are rusting. The amount of water in this bottle—about one-fifth—will be approximately equal to the amount of oxygen

removed from the air to form the rust.) Test for the presence of oxygen in each bottle by lifting the bottles from the pan and immediately inserting a burning splinter or match into each. The splinter or match should glow longer in the jar without iron filings. Does oxygen combine with iron to form rust? (Yes.)

3. **Heat.** Wet the inside of two bottles and sprinkle iron filings in both. Cover the jars. Place one in the freezing compartment of a refrigerator and the other in a warm place. Leave this for 48 hours before checking the results. Does iron rust faster when the temperature is higher? (Yes.)

After the children have set up their experiments and waited for the results, have them shake and gently rub off the reddish-brown rust from these objects. They must be very careful to avoid digging into the iron that has not rusted. They might also bring rusted objects to school and remove the rust from them. Have the class test this rust to determine whether it is magnetic. (It is not. Iron and oxygen have combined to form one kind of iron oxide. The characteristics of this kind of iron oxide are not the same as iron.)

In some chemical changes, an element replaces another element in a compound and a different element and compound are formed. The following materials will be needed: small pieces of zinc (Zn), hydrochloric acid (HCl), a large soft drink bottle, a pan, and a balloon. Ask the children to *predict* what kind of gas will be released from the hydrochloric acid molecules if a zinc atom replaces one of the atoms in the hydrochloric acid. (Either hydrogen or chlorine gas.) Take the class to the school library to find information about the characteristics (how they act) of hydrogen and chlorine gas, so that they will know which kind of gas they release when they do this experiment. Let one of the children set the soft drink bottle in a pan of water and cover the bottom of the bottle with zinc chips. The pan of water is used as a safety measure to decrease the possibilities of the bottle breaking, as a result of the heat released when the hydrochloric acid reacts with the zinc. Zinc chips can be made by cutting the metal layer, underneath the layer of cardboard, in an old dry cell into small pieces. The extra pieces of zinc left over from this experiment can be stored in jars in the science equipment and supply room. Have a second child cover the zinc in the bottom of the soft drink bottle with water. This next step in the experiment may be done by either the teacher or a child. If a child does it, the teacher should demonstrate how to remove and hold the stopper and how to pour the acid so carefully that none gets on the outside of the soft drink bottle (see Fig. 10.2).

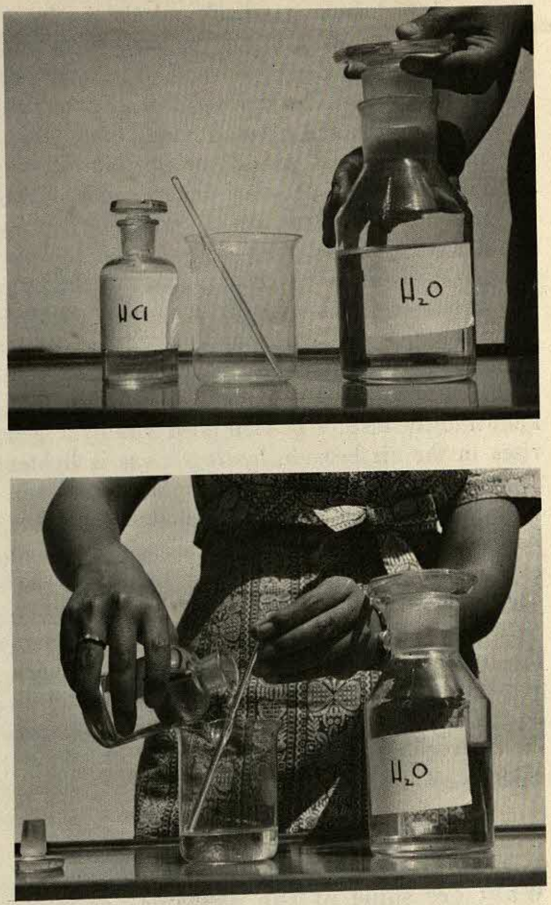


Fig. 10.2 How to pour acids.

Very carefully pour some hydrochloric acid into the soft drink bottle. The amount of acid should approximately equal the amount of water in the bottom of the bottle. Have one child hold the bottle very firmly while another child stretches the neck of a balloon over its top. The balloon will begin to inflate almost immediately. When the balloon feels *firm*, twist the neck of the balloon several times, so that the gas will not escape, and remove the balloon. Unwind several feet of sewing thread from its spool and tie the loose end around the neck of the balloon. Place the spool and balloon on the table. The balloon will rise to the ceiling. The children will want to pull the balloon down and release it many times. Take the balloon outdoors to find out how high it will go. Try to find an open area or some spot on the playground where there are no trees, in order to avoid having the children disappointed by loss of their balloon in a tree top. Ask the children which gas (chlorine or hydrogen) was released when the zinc combined with one of the atoms in the molecules of hydrochloric acid? (It was hydrogen.) Hydrogen is the lightest-weight gas known to chemists. A balloon filled with hydrogen rises in the air because hydrogen gas is lighter than air. The second lightest-weight gas, helium, is usually used to fill large balloons and other kinds of lighter-than-air craft because it does not explode as hydrogen does. Ask the class what chemical change occurred in this experiment. (The zinc atom replaced the hydrogen atom in the hydrochloric acid molecule. Two hydrogen atoms combined to form a molecule of hydrogen, H_2. The zinc combined with the chlorine atom in the hydrochloric acid molecule and formed zinc chloride, ZnCl.)

6. How common are chemical changes? What are some of the chemical changes that are occurring all around us?

In the preceding inquiry, the children learned that rust was a kind of oxidation. They know also that an oxygen atom combined with two hydrogen atoms makes a water molecule (H_2O) and that a carbon atom combined with two oxygen atoms makes a carbon dioxide molecule (CO_2). Encourage the class to tell why they think oxygen combines with so many things. Since oxygen is in air, water, and soil, it comes in contact with many substances. Because oxygen combines readily with so many substances, chemists call it an *active element.* Whenever the element oxygen combines with another substance, the process is called *oxidation.* Both plants and animals must oxidize food for energy and growth; this kind of oxidation is called *slow oxidation.* Rapid oxidation, called *combustion,* occurs when fuels burn.

One of the most common compounds formed when food is oxidized is carbon dioxide. Both plants and animals give off carbon dioxide as a waste product. Children can have many experiences to help them develop concepts about this gas and its prevalence in their environment.

Carbon dioxide is so abundant and safe to use that it is frequently utilized to extinguish some kinds of fires. (See Chap. 9, Inquiry 1.)

Limewater is calcium hydroxide $Ca(OH_2)$, a saturated solution of slaked lime used to test for the presence of carbon dioxide. Prepared limewater can be bought at a drug store, or you can buy calcium oxide (CaO) in tablets or powder and dissolve it in water to make limewater. To get a saturated solution, continue adding calcium oxide tablets or powder to the water and stirring the mixture until the water dissolves no more of the chemical. Caution the children to wash their hands throughly after handling the dry calcium oxide. Pour the limewater solution through a filter paper to remove the excess chemical. After the solution passes through the filter paper, it should be as clear as water. Store the solution in a tightly stoppered bottle and be sure to keep the bottle full. If the storage bottle is not kept full of limewater, the solution will turn milky.

The children know that carbon dioxide can be made by combining baking soda with vinegar. Use these materials again to make more of this gas. Make it in a flask, or a soft drink bottle that has been fitted with a one-hole stopper, a piece of glass tubing, and a piece of rubber tubing fitted on the upper end of the glass tubing. Let the carbon dioxide gas, formed by the baking soda and the vinegar, bubble from the end of the rubber tubing into the limewater.

Observe that the clear limewater changes to a cloudy solution. If the children look very closely, they will see tiny white particles of calcium carbonate ($CaCO_3$) in the solution. When calcium hydroxide combines with carbon dioxide, it forms calcium carbonate and water. The class should understand that chemists use this test to detect the presence of carbon dioxide.

Ask the children now why the limewater bottle should be kept full. (The air above the solution contains carbon dioxide, which will react with the limewater to turn it milky.)

With the aid of limewater, the children can become chemical detectives searching for evidences of carbon dioxide and the chemical changes that are producing it. Encourage the class to plan their own experiments to answer questions like the ones that follow. In each experiment they do, have them compare the limewater they used to test for the presence of carbon dioxide with the bottle of limewater that is tightly stoppered.

How can we find out whether carbon dioxide is present in:

1. Air in classrooms ?
2. Air out of doors ?
3. Exhaled air ?
4. Dry ice ?
5. Soft drinks ?

How can we find out whether carbon dioxide is present in gases released from:

1. Burning fuels ?
2. Decaying plants and animals ?
3. Yeast growing in a warm sugar solution ?
4. A mixture of baking soda and sour milk ?
5. A mixture of baking powder and water ?

The results of these experiments will show that carbon dioxide is present; but even though the children can predict the results correctly before doing the experiment, it is important for them to *check their predictions*. The *abilities* the children show *in solving the problems* are one measure of *their progress* in the techniques of problem solving.

Rocks and minerals are subjected to both chemical and physical changes. The minerals in some rocks oxidize when they dissolve or "go into solution." When these kinds of minerals dissolve, they are chemically changed. Other kinds of minerals in rocks dissolve without undergoing any chemical change. The process of dissolving can be either a chemical or a physical change. Have the children examine the surface of rocks. Scrub the rocks with soap and water and a brush. After the rocks are thoroughly dry, break the rocks into several pieces so that the children can observe the difference between the inner and outer surfaces of these pieces. Discuss why the inner and outer surfaces look different. (A chemical change—oxidation—may have occurred on the outer surface.) Some of the minerals may have dissolved without any chemical change and left small openings in the surface of the rock.

Try to find a four- or five-pound piece of high quality limestone ($CaCO_3$). Break off a small piece for a control and place the large piece on the surface of a coal fire and leave it overnight. The building custodian may be able to help the children with this experiment. Ask him if he will put the limestone in the school furnace. After the limestone has been heated, place it in a pail and bring it into the classroom.

Compare the small piece of limestone, that was not heated, with the large piece. What evidence of change can be seen? (The heat will have changed the appearance of the large piece of limestone. The heated piece should break more easily and the white parts will look and act like chalk. The white parts have been chemically changed into calcium oxide, CaO.)

After the children have observed the differences between the two pieces of limestone, break off a small piece from each of the two samples. Place the heated and unheated pieces in separate jars of water. Observe which piece dissolves more readily. (The piece that was heated dissolves more readily.) Dip water from each container and put each sample of water in a separate jar. *Think of a way to find out* whether any lime (calcium oxide) has dissolved in the water. (If lime has dissolved in water, exhaled air will turn the limewater milky or cloudy.)

If the children can make this prediction, they are able to use *a previous learning in a new situation*. This method can be used to discover whether the learning has become an understanding or whether it is just another fact that will soon be forgotten. A sample of water taken from the jar containing the heated limestone will become milky when the children exhale into it through soda straws. The sample of water taken from the jar containing the unheated limestone will not turn milky. The jar of water containing the heated limestone has calcium oxide in it. Some of the molecules of calcium carbonate ($CaCO_3$) in the limestone changed into calcium oxide (CaO) and carbon dioxide (CO_2) when the stone was heated. Have the children save this limewater for future use in detecting the presence of carbon dioxide.

Ask some members of the class to find out how iron ore differs from the pig iron that comes from the blast furnace in a steel mill. Perhaps they can discover the chemical change that occurs in the iron ore. Other children might find out how cement is made from limestone and the chemical change that occurs in the cement kiln. Still other children could find out if a chemical change occurs when cement, sand, stone, and water are used to make cement blocks, walks, and highways.

Ground water and the chemicals in it cause chemical and physical changes in rocks. Put drops of vinegar or hydrochloric acid on limestone, marble, and other kinds of rocks. Observe which rocks show a reaction when the acid is applied to them. (The children should realize that the bubbles of gas which form on the limestone and marble are evidences of chemical changes.) Encourage them to discover that this gas is carbon dioxide. They should be able to devise an experiment to do this.

Surface waters contain dissolved carbon dioxide. Carbonated water dissolves many substances more readily than pure water (water that does not contain chemicals in solution). Wash a piece of limestone, dry it, and break it into pieces. Put one piece in a jar of drinking water; put the second piece in a jar containing carbonated water (soda water). Stopper both jars tightly and leave the jars for several days. At the end of this period of time, examine the two pieces of rock with a magnifying glass. Look for any changes that may have occurred to these two pieces of rock. (The children should be able to see small openings in the rock placed in the carbonated water. These openings in the rock are the spaces that were formerly filled with pure limestone or calcium carbonate. The calcium carbonate changed into another compound as it dissolved in the carbonated water. The children may be able to see tiny grayish-white flakes of this compound in the water. They may also be able to see undissolved particles of impure limestone.)

Green plants are chemical factories. With the aid of sunlight, the chlorophyll present in the leaves changes carbon dioxide, water, and the mineral (nitrate) dissolved in the water into starches, sugars, fats, and proteins. During this process of food making, oxygen is released into the air. (It might be well to emphasize at this point that oxygen is released during the food-making process but that both plants and animals oxidize food for the growth and energy needed for carrying on life processes and that carbon dioxide is a by-product. Frequently the food-making process of green plants is overemphasized and children develop the misconception that only animals and nongreen plants oxidize food.)

7. How important are chemical changes? How can they be controlled?

Discuss the importance of chemical changes in maintaining balance in our world. Questions like these may help to direct the discussion.

What difference would it make:

1. If people and animals did not release carbon dioxide to the air? (The green plants would lack the carbon dioxide they need for food making. The nongreen plants and all living things that are unable to make their own food would die. Eventually, there would be no living things on the earth.)
2. If green plants did not release oxygen to the air? (There would not be enough oxygen for other kinds of living things to oxidize their food. These living things would die, and soon the green plants would not have enough carbon dioxide to make food so they would also die.)
3. In fire control, if there were more oxygen present in the air? (Combustion or oxidation would occur more rapidly. More men would be needed to help control fires, and more fire extinguishers would be needed. More forests would burn each year.)
4. If there were not enough oxygen in the air to burn fuels? (Our present methods for burning fuels would change. Scientists would find a way to burn fuels by adding the necessary amount of oxygen to the air.) The children might enjoy discussing some of the changes that might need to be made in automobiles, stoves, furnaces, and alcohol and kerosene lamps in order for them to burn fuels. Remind them that since matches would not burn, fires could not be started with matches. The gas from cigarette lighter fluid would not ignite. Flint could be used, but the fuels would have to be supplied with the correct amount of oxygen.
5. If dead plants and animals did not decay? (The mineral content in the soil would soon be depleted. The dead plants and animals would crowd out all other living things on the earth.)

The children might also discuss some of the ways man delays or prevents chemical changes.

Because chemical changes occur when foods spoil, the children can list and experiment with the various methods people use to delay or prevent food spoilage. They might discuss some of the following methods: refrigeration, smoking, canning, dehydration, and radiation. They might also discuss the use of food preservatives, such as salt, sugar, spices, and chemicals.

Metals are subject to chemical changes too. Have the children read about the corrosion of metals and about how scientists are attempting to control this kind of chemical change.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Scientists use the molecular theory to explain the fact that solid, liquid, and gaseous substances expand, contract, and change their physical form.

2. The molecular theory is well substantiated.

3. Molecules are composed of two or more atoms. Some molecules are made of a great number of atoms, and are, therefore, relatively large.

4. There are more than 100 known elements. A very great number of molecules have been formed from the different elements. Scientists who are working with atoms make new and different molecules all the time.

5. During a *chemical change,* atoms change places to form new and different molecules. There are many types of chemical change.

6. Chemical changes occur all about us. Oxidation, fermentation, decay, and photosynthesis are common chemical changes.

7. Many chemical changes are helpful; others are harmful. People know how to delay, prevent, and increase certain chemical changes.

Chapter Eleven

Protons, Neutrons, and Electrons

INQUIRIES

1. What is inside an atom?

2. How do the atoms of elements differ?

3. What elements are radioactive? What is happening in radioactive materials? How can they be identified?

4. What is nuclear energy? What is nuclear fission? What is a chain reaction? What are nuclear reactors? How are they controlled?

5. What is fusion? How does it differ from fission? How does a hydrogen bomb (nuclear fusion) release energy?

6. How has nuclear energy been put to worthwhile purposes? Who should determine its use?

1. What is inside an atom?

Help the children make a survey of what they have learned about atoms. Children who have heard about *protons, neutrons,* and *electrons* may have started to form concepts about them. Some children also have concepts about the electron cloud around the *nucleus* of the atom. Encourage the pupils to use these original concepts to form *their own theories* about the structure of an atom. After the pupils have *recorded* their theories, ask them to do some reading about the structure of atoms. Reading can help them to find out whether their original theories are correct and to expand their understandings. Follow up their reading by having them *reevaluate* their recorded statements about the structure of the atom.

If this reading motivates the pupils to *compare* the structure of *atoms* with the structure of the *solar system*, ask them to make models of each for the bulletin board. These models should show the sun as the center of the solar system and the nucleus as the center of the atom. It should show the nine known planets revolving in ellipses about the sun and the electrons revolving in ellipses about the nucleus. Some books may use the term *planetary electrons.* The models should emphasize *the great amount of space* in the solar system and *the great amount of space* within the atom. Discuss the gravitational attraction between the sun and the planets (see Chap. 20, Inquiry 7) which holds the solar system together. Have the children predict, if they have not already read about it, that there must be an attraction between the nucleus and the electrons that keeps the electrons from escaping.

Ask the pupils to make a scientific guess about the nature of the attraction between the nucleus and the electrons. From the word *electrons*, the children may guess that the attraction is electrical. Ask them to verify this by reading science books. From resource books and films they will be able to find the following information. Within the atom, positive and negative charges attract each other and keep the atom in balance. Scientists now know that the nucleus of the atom carries the positive charges of electricity and the planetary electrons, the negative charges. They will also find that the number of negative charges balances the number of positive charges and that the nucleus is made up of different particles. Two of the particles present in the nucleus are called *protons* and *neutrons.* There are other particles in the nucleus, but these two are basic for understanding nuclear energy. Some children may wish to pursue a more detailed study of the nucleus of the atom. Each proton carries a positive (+) charge of electricity. Each planetary electron has a negative (−) charge of electricity. In a balanced atom, the number of protons equals the number of electrons. The neutrons carry no electrical charge. As the name *neutron* implies, it is neutral. The number of neutrons in the nucleus varies. The most common kind of hydrogen (H) atom has one proton and one electron and no neutron. It is the only kind of atom that has no neutron. The atoms of some elements have the same number of neutrons as protons, but many have more neutrons than protons. The protons and neutrons in the nucleus are grouped together so that there is much less space between them

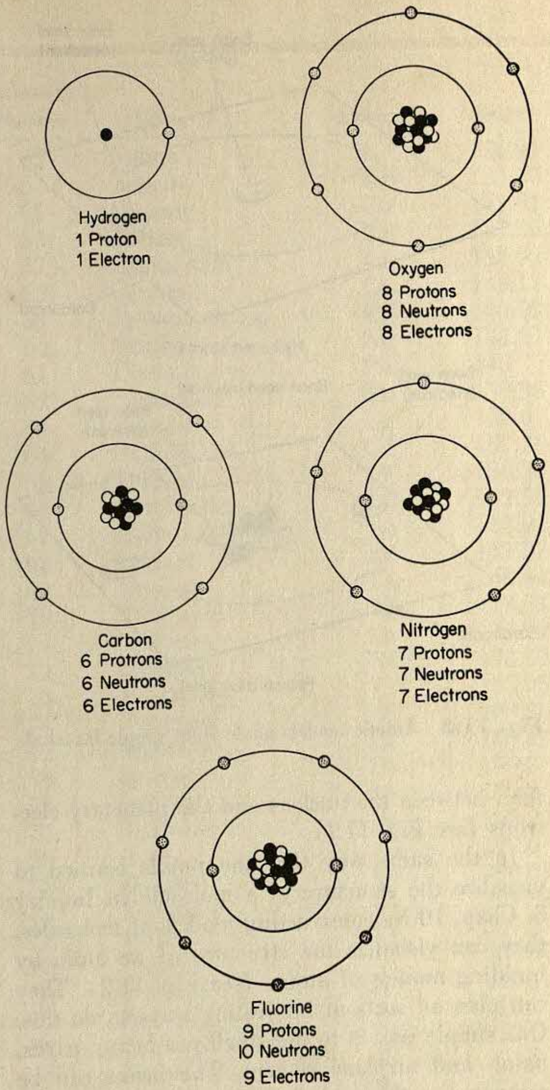


Fig. 11.1 The structure of several atoms.

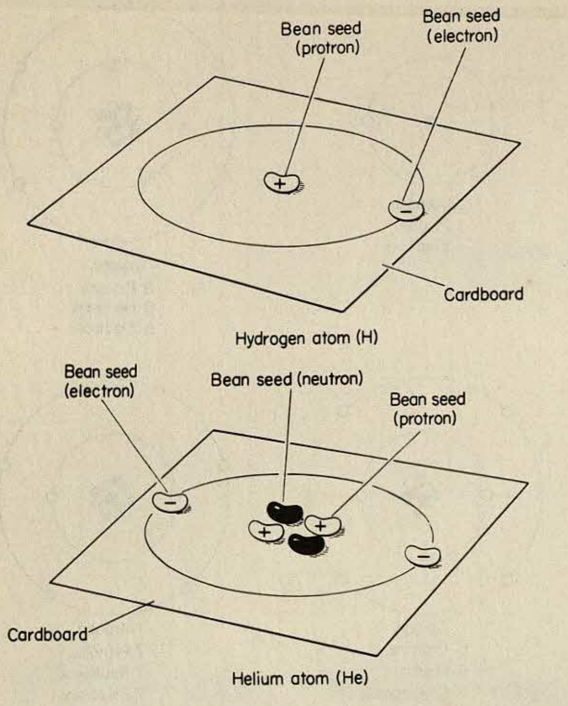


Fig. 11.2 Atomic models made from simple materials.

than between the nucleus and the planetary electrons (see Fig. 11.1).

In the same way that the pupils learned to visualize the structure of a molecule in Inquiry 3, Chap. 10 by constructing models of molecules, they can visualize the structure of an atom by building models of atoms (see Fig. 11.2). They can plan all sorts of interesting ways to do this. One simple way is to use small pea beans, cards, paint, and airplane cement. The beans can be cemented to the card. A touch of different colors of paint on the beans will help to identify them as different kinds of particles (protons, neutrons, and electrons).

2. How do the atoms of elements differ?

The children should be encouraged to discuss this problem and to form a *hypothesis* that *the atoms of different elements vary only in the number of protons, neutrons, and electrons which they contain.*

At this time, have the children look at Fig. 11.1 and Table 11.1 and explain to them that the *atomic number* tells the number of protons or planetary electrons (always the same for a balanced atom). For example:

Atomic Number	Element	Electrons	Protons
1	Hydrogen (H)	1	1
6	Carbon (C)	6	6
8	Oxygen (O)	8	8
17	Chlorine (Cl)	17	17
53	Iodine (I)	53	53
88	Radium (Ra)	88	88
92	Uranium (U)	92	92

Also explain that the number of neutrons in an atom can be determined by subtracting its atomic number from its atomic weight. This can be done because the weight of an atom is concentrated in the nucleus and because the weight of electrons is infinitely small.

Element	Atomic Weight		Protons		Neutrons
Hydrogen (H)	1	–	1	=	0
Carbon (C)	12	–	6	=	6
Oxygen (O)	16	–	8	=	8
Chlorine (Cl)	35	–	17	=	18
Iodine (I)	127	–	53	=	74
Radium (Ra)	226	–	88	=	138
Uranium (U)	238	–	92	=	146

Some children may want to work out the number of electrons, protons, and neutrons for the complete list of elements. Other children may want to try constructing models of many elements.

3. What elements are radioactive? What is happening in radioactive materials? How can they be identified?

The children need to understand the words *radioactive, radioactivity,* and *radiation.* Have them go to more than one source for definitions of these words. Provide time for them to compare their findings and to discuss what the definitions mean to them. Encourage them to put the definitions into simple statements. Children may make sentences like the following about radioactivity: The atoms of some elements, like radium and uranium (U235), are naturally radioactive. *Radioactive* atoms are unstable and break up spontaneously. Sometimes the words *explode, dis-*

Table 11.1

ELEMENTS

Atomic Number	Name	Symbol	Weight
1	Hydrogen	H	1.008
2	Helium	He	4.003
3	Lithium	Li	6.940
4	Beryllium	Be	9.013
5	Boron	B	10.82
6	Carbon	C	12.011
7	Nitrogen	N	14.008
8	Oxygen	O	16.000
9	Fluorine	F	19.000
10	Neon	Ne	20.183
11	Sodium	Na	22.991
12	Magnesium	Mg	24.32
13	Aluminum	Al	26.98
14	Silicon	Si	28.09
15	Phosphorus	P	30.975
16	Sulfur	S	32.066
17	Chlorine	Cl	35.457
18	Argon	Ar	39.944
19	Potassium	K	39.100
20	Calcium	Ca	40.08
21	Scandium	Sc	44.96
22	Titanium	Ti	47.90
23	Vanadium	V	50.95
24	Chromium	Cr	52.01
25	Manganese	Mn	54.94
26	Iron	Fe	55.85
27	Cobalt	Co	58.94
28	Nickel	Ni	58.71
29	Copper	Cu	63.54
30	Zinc	Zn	65.38
31	Gallium	Ga	69.72
32	Germanium	Ge	72.60
33	Arsenic	As	74.91
34	Selenium	Se	78.96
35	Bromine	Br	79.916
36	Krypton	Kr	83.80
37	Rubidium	Rb	85.48
38	Strontium	Sr	87.63
39	Yttrium	Y	88.92
40	Zirconium	Zr	91.22
41	Niobium	Nb	92.91
42	Molybdenum	Mo	95.95
43	Technetium	Tc	99
44	Ruthenium	Ru	101.1
45	Rhodium	Rh	102.91
46	Palladium	Pd	106.4
47	Silver	Ag	107.880
48	Cadmium	Cd	112.41
49	Indium	In	114.82
50	Tin	Sn	118.70
51	Antimony	Sb	121.76
52	Tellurium	Te	127.61
53	Iodine	I	126.91
54	Xenon	Xe	131.30
55	Cesium	Cs	132.91
56	Barium	Ba	137.36
57	Lanthanum	La	138.92
58	Cerium	Ce	140.13
59	Praseodymium	Pr	140.92
60	Neodymium	Nd	144.27
61	Promethium	Pm	145
62	Samarium	Sm	150.35
63	Europium	Eu	152.0
64	Gadolinium	Gd	157.26
65	Terbium	Tb	158.93
66	Dysprosium	Dy	162.51
67	Holmium	Ho	164.94
68	Erbium	Er	167.27
69	Thulium	Tm	168.94
70	Ytterbium	Yb	173.04
71	Lutetium	Lu	174.99
72	Hafnium	Hf	178.50
73	Tantalum	Ta	180.95
74	Tungsten	W	183.86
75	Rhenium	Re	186.22
76	Osmium	Os	190.2
77	Iridium	Ir	192.2
78	Platinum	Pt	195.09
79	Gold	Au	197.0
80	Mercury	Hg	200.61
81	Thallium	Tl	204.39
82	Lead	Pb	207.21
83	Bismuth	Bi	209.00
84	Polonium	Po	210
85	Astatine	At	210
86	Radon	Rn	222
87	Francium	Fr	223.0
88	Radium	Ra	226.05
89	Actinium	Ac	227
90	Thorium	Th	232.05
91	Protactinium	Pa	231
92	Uranium	U	238.07
93	Neptunium	Np	237
94	Plutonium	Pu	242
95	Americum	Am	243
96	Curium	Cm	245
97	Berkelium	Bk	249
98	Californium	Cf	249
99	Einsteinium	E	253
100	Fermium	Fm	254
101	Mendelevium	Mv	256
102	Nobelium	No	253
103	Lawrencium	Lw	257

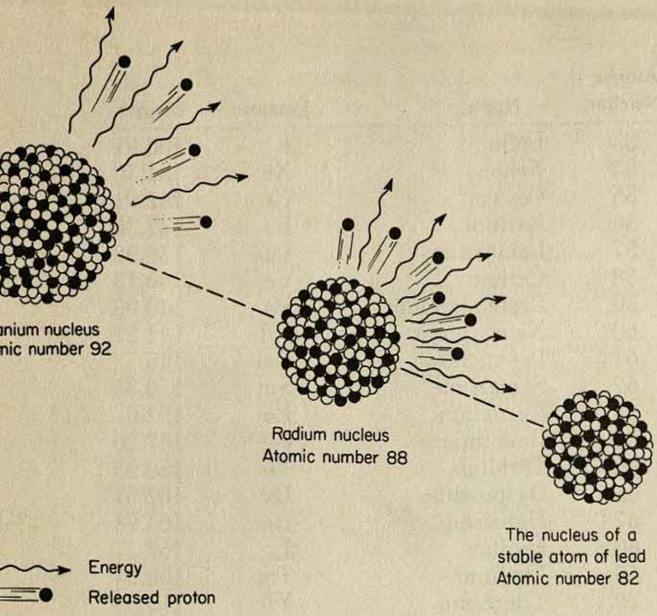


Fig. 11.3 Uranium slowly changes to lead.

integrate, and *decompose* are used to mean the same thing. When a radioactive atom breaks up, it throws off some of its particles (protons, neutrons, and electrons) and some very powerful rays. Because the number of protons, neutrons, and electrons remaining in the atom is less, the atom changes into an atom of a different element. See Fig. 11.3. *Radioactivity* is the spontaneous breaking up of radioactive atoms and the giving off of rays. *Radiation* is the term used for the rays that are given off. This *radiation* is a very powerful form of energy. Doctors treat patients with the energy from the radiation given off by radium and radioactive medicines. The energy from the radiation of the radioactive "fallout" material of an atomic explosion can be very dangerous. Because radioactive materials are too dangerous to be handled directly, they are removed from the reactor by remote-controlled, mechanical hands.

From their resource books and films, the pupils will have discovered that many scientists contributed to the understanding of radioactivity. Their discoveries helped other scientists to discover about the releasing of the great energy within radioactive atoms and the using and controlling of this energy. Scientists from many countries are gradually discovering more and more about the atom. The following list of famous scientists illustrates that scientific knowledge is the accumulation of the findings of many people. Ask each of the children to choose a scientist from the list and find what this scientist contributed to the releasing of the atom's energy. They should find the date of the discovery, so that the information can be arranged in chronological order. The country in which each scientist lived or worked when he made his discovery should be noted.

SCIENTISTS WHO HELPED UNLOCK SECRETS OF RADIOACTIVE ATOMS AND RELEASE THE ATOM'S ENERGY

Henri Becquerel
Niels Bohr
Pierre and Marie Curie
Albert Einstein
Enrico Fermi
Otto R. Frisch
Hans Geiger
Otto Hahn
Lise Meitner
Sir Ernest Rutherford
Harold Urey

The pupil who reports on Henri Becquerel will tell how he discovered that uranium ore gave off radiations, which could not be seen, but which could be recorded on photographic paper in the same way light rays can be recorded.

Encourage the class to invent and plan experiences similar to those which follow in order to reproduce the experiments of Henri Becquerel. At a photographic supply store, buy a small package of contact paper and small containers of chemicals, which children can mix with water to develop and fix an image on this paper. If velite contact paper is used, the children need not work in a dark room. If they use other contact paper, they must work in a dark room or in a room or closet that has no windows. There they can work under a red light bulb or a "safe light."

When the chemicals have been mixed and the two necessary pans of wash water are ready, open the package of paper. Tear one sheet into two pieces. Put one-half of the sheet back into the package and put the package in a place where there will be *no light*. Feel the other half. The side with the chemicals on it feels smooth; the other side feels rough. Hold the paper with the smooth side up and shine a white light on it for a few seconds. Turn off the light. Remove the other half sheet from the dark and put both halves, smooth side up, in the developer solution. What happens to the chemicals on the half that was exposed to light? (They turn dark.) What happens to the control half that received no light? (It stays white.) Remove both pieces from the developer. Wash quickly in a pan of water and put them in the second solution to fix the chemicals. When the exposed paper is developed and fixed, wash it thoroughly in running water, and dry.

Ask each child to provide a small object, such as a paper clip, ring, coin, leaf, and so on. Give each child a small piece of the paper and have each lay his object on top of the smooth side of the paper. Expose each paper and its object to white light. Turn off the light, remove the object from the paper, and develop and fix the image on the paper. The children have seen that the chemicals on photographic paper turn dark when exposed to light rays.

Test the radioactive material used in the paint on clocks and watches with luminous dials that can be seen in the dark. Lay one of these watches or clocks face down on a piece of photographic paper. Expose the paper to the radiations released by radioactive paint for the same length of time that the paper in the previous experiment was exposed to white light. If there is no image on the paper, expose another piece for a longer period of time. Continue the exposure until the rays (radiation) from the radioactive material darken the paper. (The exposure may be as long as two or three days, depending upon the amount of paint used and the amount of radioactive material in the paint.)

If your school has a sample of uranium ore, or if you can borrow a sample from someone in your community, lay it on your photographic paper and find out whether the radiation from it will affect the chemicals on the paper. (The paper may need to be exposed to the ore in a dark room for two or three days.)

Borrow a Geiger counter and listen to the radiation clicks from the sample of uranium ore and from the radioactive material on a watch.

4. What is nuclear energy? What is nuclear fission? What is a chain reaction? What are nuclear reactors? How are they controlled?

Many older children have heard or read about Einstein's equation $E=mc^2$. They will be interested to learn how this equation helps scientists to estimate the amount of energy that will be released by a given amount of atomic fuel. Scientists need this information in order to determine the amount of atomic fuel required to operate atomic submarines, for example. Help the children increase their understanding of the vast amount of energy that can be released by one pound of uranium. Let them solve the equation $E=mc^2$. To do this, they need to know that E stands for energy; m for the mass of the substance; and c^2 for a constant multiplied by itself. This constant is the figure for the speed of light (186,000). The large figure they get when they multiply 186,000 by 186,000 by 1 pound will impress the class and increase their appreciation of the vast amount of energy released by a small amount of atomic fuel.

From their reading, have the children quote statistics about the energy in one pound, one thimbleful, or any quantity of uranium their books use as illustrations of the small amount of mass and the tremendous amount of energy. Have them try to find out the size of the atomic fuel mass in atomic submarines and how far this fuel will carry the submarine before it must be refueled.

The students have learned that nearly all the atomic weight of an atom is contained in its nucleus (protons and neutrons). They should discuss the fact that, for this reason, the nucleus contains most of the mass. This should help them to understand that most of the atom's energy is in the nucleus and is, therefore, called *nuclear energy* by scientists rather than atomic energy.

The students have seen that radioactive materials, like the luminous paint and uranium ore, released energy which changed the chemicals on photographic paper and caused the Geiger counter to click. This was a natural and gradual release of nuclear energy.

The following are samples of the scientific information students may be expected to have or to discover when they are working on this inquiry. Scientists found a way to release nuclear energy in one big explosion (the atomic bomb) and a way to control the rate of the fission (the atomic furnace or reactor). Before they could accomplish these things, scientists had to learn how to split the nuclei of fissionable atoms with neutron bullets in a process called *nuclear fission*.

A piece of uranium ore contains uranium atoms that have different weights. The more common kind of uranium atom in the ore is called U238. The less common atom in this ore is called U235. These two kinds of atoms are called uranium *isotopes*. The word *isotope* is used to differ-

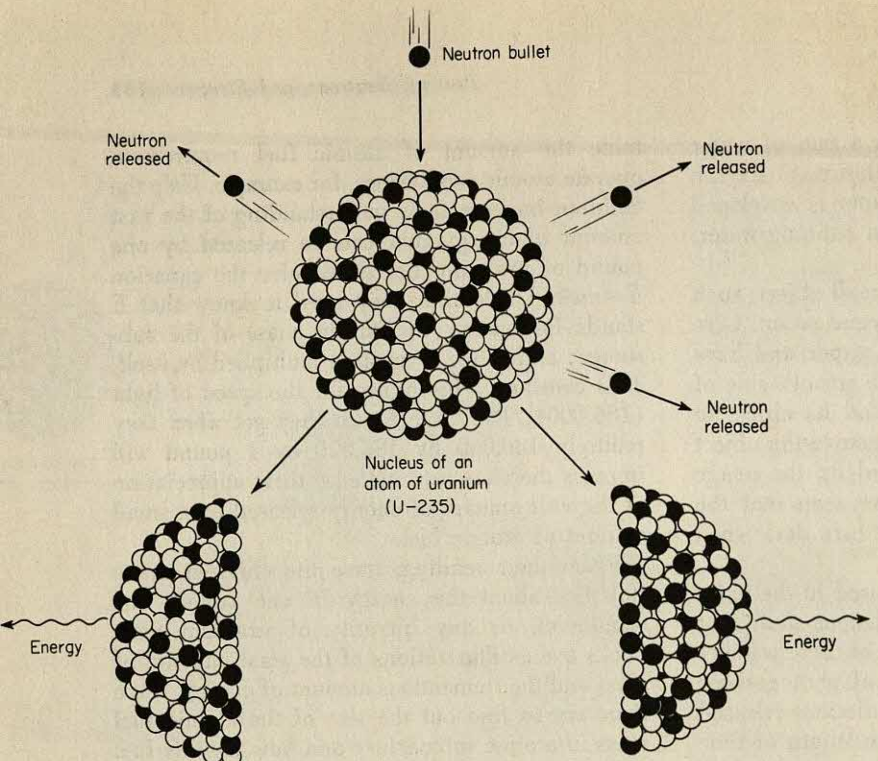


Fig. 11.4 A neutron bombards a uranium atom and causes its fission.

entiate between the atoms of different weight that are present in an element. The numbers that follow the symbol for the element represent the *atomic* weight of that particular isotope. U238 contains three more neutrons than U235. Isotopes of elements that are radioactive are called *unstable* because the nuclei of these atoms give off rays and particles. The nuclei of a few kinds of unstable, or radioactive, isotopes split, or *fission* (see Fig. 11.4). U238 is a *stable* isotope of uranium; it is not naturally radioactive. U235 is an unstable isotope of uranium; it is naturally radioactive. The nucleus of the uranium isotope U238 contains 92 protons and 146 neutrons. The nucleus of the uranium isotope U235 contains 92 protons and 143 neutrons. U235 must be separated from U238 before it can be used as a source of nuclear energy. The isotope, U235, was first separated in useful quantities from the isotope, U238, at the Oak Ridge, Tennessee, atomic energy plant.

Plutonium 239 is another fissionable element. Plutonium is made from U238 at the atomic energy plant in Hanford, Washington. Its nucleus contains 94 protons and 145 neutrons. Another fissionable isotope is uranium U233. This isotope is made from the element thorium.

U233, U235, and Pu239 are all fissionable and will split spontaneously. In this spontaneous fission, some neutrons are set free from the nucleus and serve as bullets which strike and split more and more nuclei. This is called a *chain reaction.*

Have the students read about the demonstration, with mouse traps and ping pong balls, which is used to show chain reaction; they may wish to set up and try this demonstration.

At the University of Chicago, Enrico Fermi and his helpers constructed the world's first *nuclear reactor*, which started and controlled a nuclear chain reaction. At this time the reactor was called an *atomic pile* because the fissionable material within the reactor was arranged in a sort of pile. In an atomic pile, or reactor, graphite rods are placed between the fissionable material. Graphite slows down and absorbs neutrons. If the rods are pushed all the way into the pile, the chain reaction will stop. The distance that the rods are pushed inward determines the amount of fission. The reactor is shielded with thick concrete walls to prevent dangerous radiation from escaping.

Reactors produce tremendous amounts of heat, which must be removed from the reactor. One way to do this is to have a fluid carry the heat through pipes to a heat exchanger where the heat is used to produce steam. The energy from this steam can do work.

Students will profit from the experience of building a simple model reactor using a large cardboard carton and sections of different colored broomsticks for uranium and graphite rods. Rubber hose can represent the pipe which carries the heat transfer liquid.

5. What is fusion? How does it differ from fission? How does a hydrogen bomb (nuclear fusion) release energy?

Students who have worked with Inquiry 4 should understand that nuclear fission means the *splitting* of atomic nuclei. These students may be interested to learn that nuclear fusion means the *uniting* of atomic nuclei. To compare the two, fission and fusion, they might make a chart similar to Table 11.2. It charts both their differences and likenesses. The students should remember that there are three isotopes of uranium (U233, U235, and U238). U233 and U235 have lower atomic weights than U238. There also are three known isotopes of hydrogen (H1, H2, and H3). See Fig. 11.5. Two of the hydrogen isotopes are *heavier* than the more common hydrogen atom. The class learned that the more common hydrogen isotope (H1) has no neutrons. Hydrogen 2 is called *heavy hydrogen* or *deuterium*. Hydrogen 3 is called *tritium*. Have the children make models on cards of Hydrogen 1, 2, and 3. The models will show why H2 and H3 are called *heavy* hydrogen.

The children should also make card models of two helium atoms because helium is formed as a result of fusion (see Fig. 11.6).

Encourage the pupils to use their card models of hydrogen and its two isotopes to discover combinations which could produce helium if fusion could take place. They should discover for themselves that there are two combinations that could produce helium (see Fig. 11.7).

Some of the pupils may want to compute the mass which changes into energy, using Einstein's equation $E=mc^2$. In combination No. 1, helium (atomic weight 4.003) forms from the fusion of two hydrogen 2 atoms (with a combined weight of 4.028). When they subtract 4.003 from 4.028, they find an atomic weight loss of 0.025. This figure 0.025 represents the m in the equation $E=mc^2$ or the mass that is changed into energy. In combination No. 2, the loss of mass (atomic weight) will be the same. Assuming 1 pound of hydrogen is changed to helium, 0.025 pounds would be changed into energy, or 0.025 of any unit would be changed into energy. Substituting 0.025 for m in the equation and computing the energy (E) can be an interesting problem for some children.

Table 11.2
FISSION AND FUSION COMPARED

	Differences		Likenesses	
	Fission	Fusion	Fission	Fusion
Meaning	Splitting nuclei	Uniting nuclei		
Atoms used	Radioactive Heavy Uranium, plutonium	Non-radioactive Light Hydrogen	Isotopes U233, U235	Isotopes H2, H3
Started by	Neutrons hitting nuclei	High temperature, such as produced by sun or an atomic bomb		
New atoms formed			Yes; krypton, barium, others	Yes; helium
Source of energy			Mass changed to energy	Mass changed to energy
Controlled	Yes	No. Scientists hope to solve this problem		

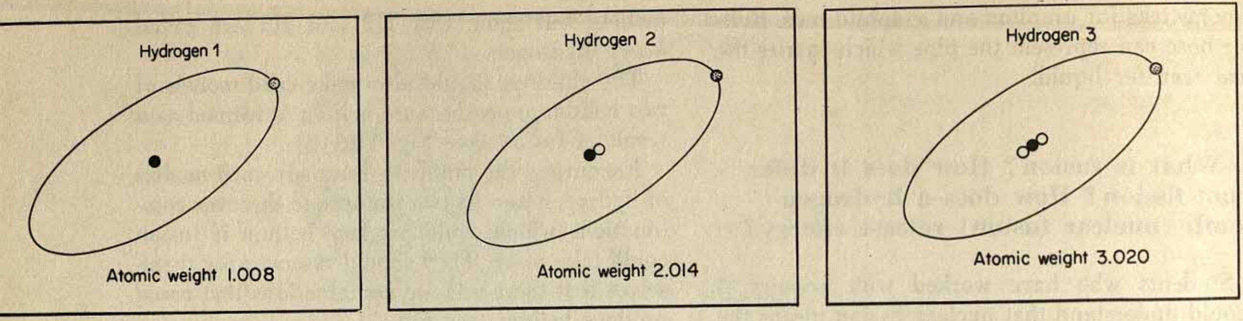


Fig. 11.5 Hydrogen isotopes. Most hydrogen atoms have one proton and one electron. Heavy hydrogen-2 isotope has one proton, one electron, and one neutron. Heavy hydrogen-3 isotope has one proton, one electron, and two neutrons.

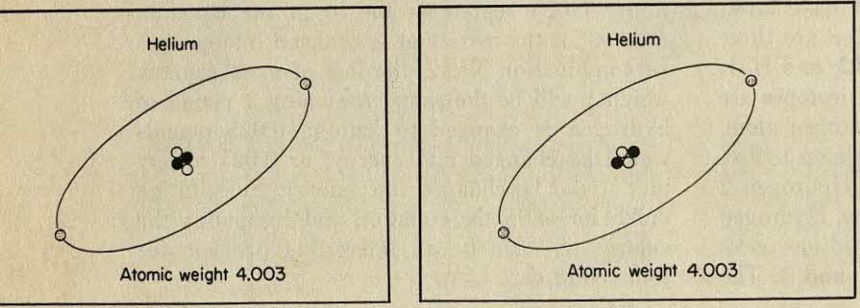
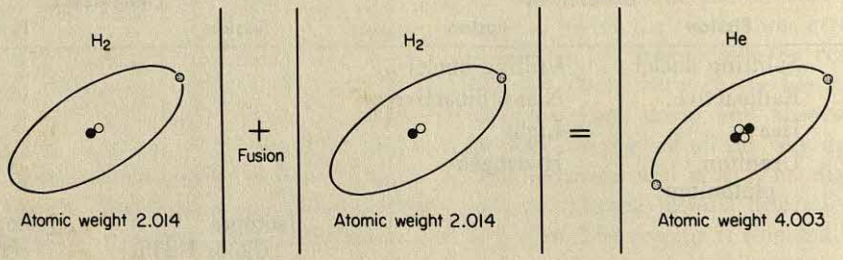
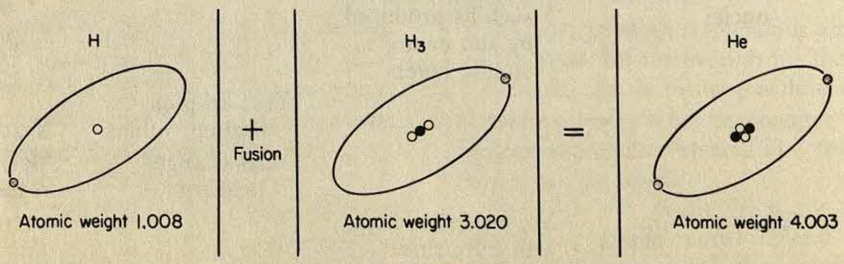


Fig. 11.6 Helium atoms have two protons, two planetary electrons, and two neutrons.

Fig. 11.7 Helium produced by fusion of hydrogen isotopes.



Combination no. 1



Combination no. 2

A nuclear fusion can be started only at temperatures of millions of degrees. The atomic bomb produces the heat to start nuclear fusion. Once started, it continues to generate heat until all its hydrogen is used. Have the pupils discuss how such tremendous heat can be made to do worthwhile work, when nuclear fusion is controlled. They should realize that this is one of the many problems on which scientists are working.

6. How has nuclear energy been put to worthwhile purposes? Who should determine its use?

Have the pupils do some research on the peacetime uses of atomic energy and report to their class what they have learned. They will find that electricity can be produced by atomic reactors and they should try to find out whether any of the electricity used in their community is produced in this way. They will know about atomic-powered submarines, ships, planes, and rockets. They will find out about radioactive isotopes used in medicine, in improving food plants and animals, and in industry.

Encourage the pupils to express their opinions about whether the potential good from nuclear energy outweighs its destructive force. They should also discuss the world's responsibility in controlling the uses of nuclear energy and what their own responsibilities may be for making decisions in the future.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Three important particles of the atom are *protons, neutrons,* and *electrons.* The protons and neutrons make a dense nucleus around which electrons rapidly revolve in ellipses. Normally, the number of protons in the nucleus equals the number of electrons revolving around the nucleus. There is an *electrical attraction* between the protons and electrons which tends to keep them in balance. The number of neutrons may or may not equal the number of protons in the nucleus of an atom. Neutrons carry no electrical charge. An atom is largely space.

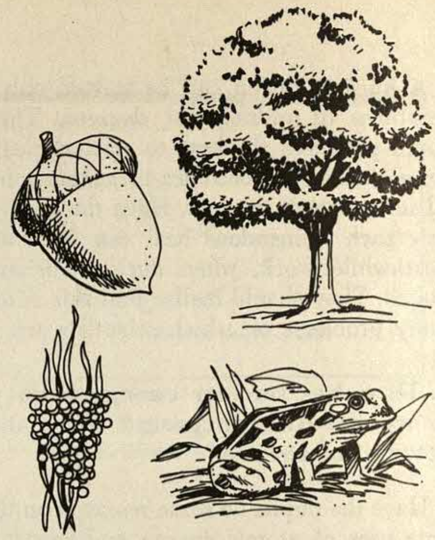
2. The atoms of elements differ from each other only in the number of their protons, neutrons, and electrons. Most of the weight and mass of an atom is in the nucleus.

3. Some elements are *radioactive.* Radioactive atoms are unstable. Some kinds of radioactive elements spontaneously break up and give off powerful rays called *radiation.* This radiation is energy. When atoms fission, they give off protons, neutrons, and electrons. This process is called *radioactivity.* During the process of radioactivity, new elements are formed.

4. *Mass or matter is changed into energy.* Because most of an atom's mass is in its nucleus, most of its energy is in its nucleus. *Atomic* energy is *nuclear* energy. Splitting a nucleus is called *fission.* Nuclear fission is one way to release nuclear energy. Chain reactions occur during fission. The explosion of an atomic bomb is an uncontrolled nuclear chain reaction. A nuclear reactor controls the rate of fission by slowing down the chain reaction.

5. *Fusion* unites atomic nuclei. Fusion is started by the heat of an atomic bomb. Energy is released when the nuclei of atoms fuse because during fusion mass is changed to energy. The explosion of a hydrogen bomb, a nuclear reaction, also generates tremendous heat energy.

6. Many worthwhile peacetime uses have been found for nuclear energy. Wise decisions for the control of nuclear energy depend upon an understanding of nuclear energy and its potentials by all the people in the world.



Chapter Twelve

Likenesses and Differences Between Plants and Animals

What Living Plants and Animals Must Have

This skeletal chapter emphasizes sample *activities* which will help children discover for themselves what *plants and animals must have to live.* Some of the activities are outlined. Others are developed in more detail. The chapter allows the teacher and children to state their own inquiries and summarize their scientific findings. After reading the activities, the teacher should outline *the inquiries,* which he will have his pupils investigate and *the scientific findings,* which he hopes they will develop. He should also plan the *process skills,* which he intends to emphasize during the investigation.

Observing and caring for pet animals

1. Find out what different kinds of pet animals the children have.
2. Plan for some of these pet animals to spend a day in the classroom.
3. Have each child help to take care of at least one animal during its visiting day.
4. Observe and discuss what each animal must have to keep alive. (Air, food, heat, and water.)

Distinguishing between constant- and variable-temperature animals

1. Touch and handle animals.
2. Note that the bodies of cats, birds, dogs, people, and so on, *feel warm.* Others, such as fish, toads, frogs, insects, turtles, *feel cool.*
3. Help the pupils define the term *constant-temperature* animals. These animals feel warm. Their temperatures are *nearly constant* from one day and one season to the next.

4. Help the pupils define the term *variable-temperature* animals. These animals feel cool. Their temperatures *vary* with the daily or seasonal variation in the temperature of the place in which they live.
5. Have the children make two lists of animals; one of constant-temperature animals and the other of variable-temperature animals.

Planning to collect and care for variable-temperature animals

Encourage children to make plans like the following.

HOMES FOR VARIABLE-TEMPERATURE WATER ANIMALS

Containers	Animals
Aquaria	Fish
Battery jars	Polliwogs
Plastic dishpans	Crayfish
Wide-mouthed gallon jars	Water insects
	Water snails

HOMES FOR VARIABLE-TEMPERATURE AMPHIBIANS AND REPTILES

Aquaria and plastic dishpans (Cover containers with fine wire mesh or cheesecloth to allow air to circulate freely.)	Salamanders Frogs Toads Snakes Turtles

HOMES FOR VARIABLE-TEMPERATURE SPIDERS AND LAND INSECTS

Aquaria	Spiders
Battery jars	Crickets
Wide-mouthed gallon jars (Cover containers with fine wire mesh or cheesecloth to allow air to circulate freely.)	Grasshoppers Katydids Walking sticks Praying mantises
Ant house	Ants
Fine wire mesh cage (or cage made from a roll of window screen with pie plates or coffee cans for top and bottom)	Caterpillars Beetles Butterflies Moths Flies

THINGS WE WILL NEED

Wide-mouthed jars with lids (some with holes in them)
Pails for water, sand, soil, and gravel
Small boxes for transporting insects and caterpillars
Dip nets or sieves and strainers for collecting water animals and some kinds of water plants
Butterfly nets
Newspapers for wrapping the land plants in separate bundles
Baskets for carrying plants, and small jars
Old frying pans, or pots with long handles, for washing sand and gravel
Trowels and a spade for digging land plants
Powdered charcoal
Containers which are to be used for homes

Fig. 12.1 Children need experiences with living animals. *Courtesy New York State Teachers' Association and Dr. George B. Blair.*

WHAT WE WILL WEAR

slacks
blue jeans
play clothes
old tennis shoes
rubbers
rubber boots

SAFETY RULES WE WILL OBEY

1. I will stay and work with the partner assigned to me.
2. My partner and I will stay within *talking*

distance of the adult who is our group leader. (Many teachers assign about six children to a parent who serves as a group leader. The teacher should not be responsible for any one group because he needs to be free to move from one group to another.)

3. I will do whatever my group leader tells me to do without questioning or complaining.
4. I will obey any traffic and transportation rules that are made for this trip.
5. I will leave whatever I am doing and go immediately to my teacher when he blows the whistle. (The whistle will quickly bring together all the children if the teacher wishes to show them something or if there is danger.)
6. I will show these safety rules to my parents, tell them where I am going, with whom, what time I will leave and return to school, and how I am going.
7. I will see that my group shows this list of rules to our group leader before we leave.

CONSERVATION PRACTICES WE WILL FOLLOW

1. Collect only what will be used.
2. Leave the collecting area clean and beautiful.

Stocking containers

The number of plants and animals to be placed in a container depends upon the size of the container and the size of the plants and animals.

If possible each child should stock his own aquarium. It could be a wide-mouthed glass jar.

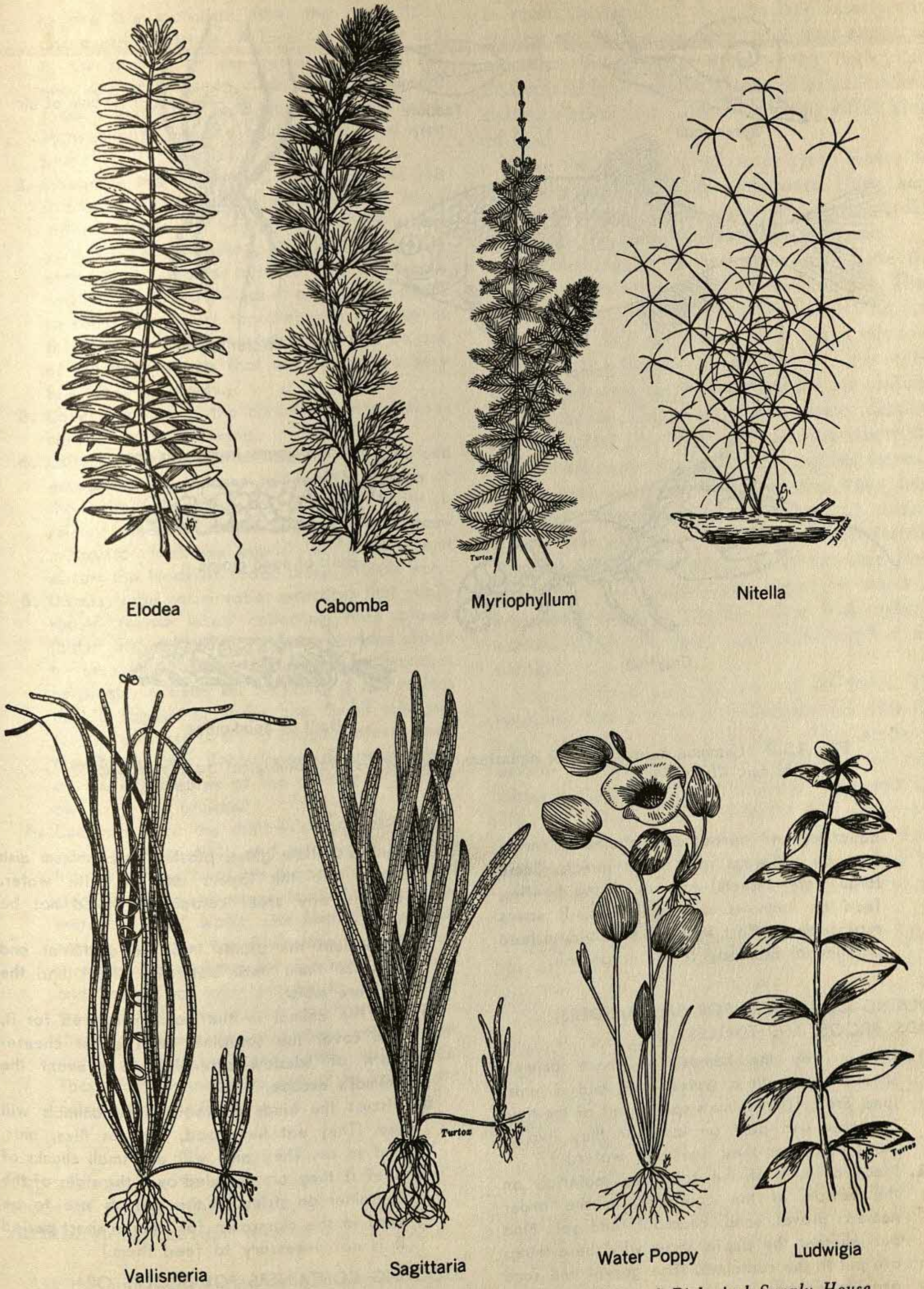
The general rule for determining the number of animals for an *aquarium* is one inch of fish to a gallon of water. Actually, however, several small minnows can be kept in this amount of water, if the minnows are taken from stagnant ponds and pools in stream beds. Minnows taken from rapidly running streams require water that contains a high percentage of oxygen. A half dozen healthy, rooted, water plants, such as an elodea and myriophyllum (see Fig. 12.2) will keep a one-gallon aquarium supplied with oxygen, if there are not too many animals in it. If the plants grow too profusely, some of them can be removed. About an inch and a half of sand and gravel is needed in the bottom of the aquarium. This provides anchorage for the rooted plants.

For a terrarium select small plants found in the meadow or along the edge of the water. The plants provide a hiding place for animals, and beautify the animal's home. The number of plants is largely a matter of taste. An estimate can be made of the amount of gravel and sand needed to provide proper drainage for the plants and for the amount of soil needed to cover the gravel and sand.

Homes for spiders and land insects do not need any special materials so long as they are supplied with fresh food each day.

STOCKING AQUARIA WITH PLANTS AND ANIMALS

1. Wash sand which is to be used in the aquarium. Stir sand in a pail that is partially filled with water. Wait a few seconds until the sand has settled. Empty the water. Add more water and repeat this procedure until the water looks clear.
2. Place a one-inch layer of sand in the bottom of each aquarium.
3. Plant the water plants in the sand and anchor them with gravel.
4. Lay a piece of paper on the plants and slowly pour some water on the paper. Continue to add water until it rises to a height of 3 or 4 inches.
5. Discuss the best location in the classroom for the aquarium. Avoid sunny windows and places near radiators.
6. Place the aquarium in a suitable location in the classroom before adding more water.
7. Several snails may be put in the aquarium before the remainder of the water is added. If possible, the water that is used should be collected from the body of water in which the plants and animals lived. If this is impossible, let the tap water stand overnight in a large pan before placing it in the aquarium. This standing period allows the chlorine in tap water to evaporate. It also allows the water to reach room temperature.
8. Add water to a height of 1 inch from the top of each aquarium. Use the same procedure that was used when the first water was poured.
9. To keep out dust, cover the top of each aquarium with glass or with transparent food wrap.
10. When the water is crystal clear, add the water animals. (See Fig. 12.3.) If the children want to have fish in one of their aquaria, encourage them to select tiny ones. Small minnows require less oxygen than larger ones; they will be more active and more likely to survive. Separate aquaria for polliwogs and water insects are most practical. Polliwogs swim along the bottom of the


Elodea

Cabomba

Myriophyllum

Nitella

Vallisneria

Sagittaria

Water Poppy

Ludwigia

Fig. 12.2 Common plants for the aquarium. *Courtesy General Biological Supply House, Inc., Chicago, Illinois.*

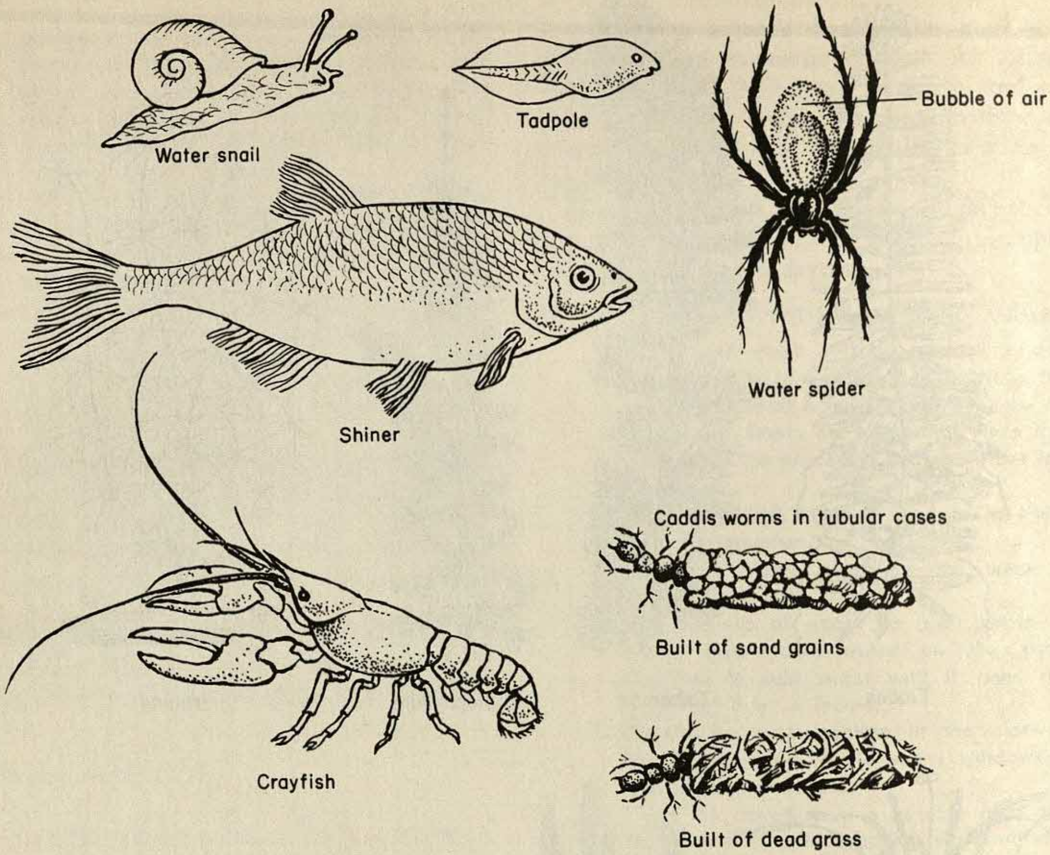


Fig. 12.3 Common animals for the aquarium. *Courtesy General Biological Supply House, Inc., Chicago, Illinois.*

aquarium and uproot the plants. Minnows feed on polliwogs and water insects. Some large water insects, such as diving beetles, feed on minnows and polliwogs. It saves replacement effort to have the children feed commercial fish food to water animals.

STOCKING CONTAINERS FOR SALAMANDERS, TOADS, FROGS, AND TURTLES

1. Discuss why the homes for these animals should have both a water area and a moist land area. (The animals spend part of the time in water and part on land, or they live in moist places or they live near water.)
2. Place a layer of the following materials on the bottom of the container in the order named: gravel, sand, charcoal, and soil. Find out whether the pupils know why these things are put in the container. (The gravel and sand provide proper drainage, the charcoal helps to prevent the growth of molds and other kinds of fungi.)
3. Push a shallow *glass, plastic,* or *aluminum* dish down into the layers and fill with water. Discuss why steel containers should not be used.
4. Transplant the plants into the container and sprinkle them until both the plants and the soil are moist.
5. Put the animal in the home prepared for it, and cover the container with either cheesecloth or window screening to prevent the animal's escape.
6. Discuss the kinds of food these animals will use. (They eat live food, such as flies, ants, and so on. They also will eat small chunks of beef it they are dangled over the sides of the container on string. If the animals are to be kept in the classroom for only a short period it is not necessary to feed them.)

STOCKING CONTAINERS FOR SPIDERS OR LAND INSECTS

1. Discuss what these animals need for good homes. (Homes for spiders and land insects

require few materials other than fresh food and a little moisture. A layer of sand or soil in the bottom of the container avoids the necessity of frequent cleaning of the animal feces and leftover food. Spiders eat live food. Many caterpillars and adult insects feed upon plants.)

2. Encourage the children to collect such animals as spiders and different kinds of insects. Many different kinds can be collected in the school yard. Crickets, grasshoppers, and katydids are very easy to care for because they eat leaves and fruits from many kinds of plants. Urge pupils to collect the insect together with a piece of the plant on which they find it. It may be one of the many insects that will eat only a very few kinds of plants.)
3. Cover the top of the containers with cheesecloth or wire screening.
4. Obtain a number of different references and encourage the children to identify as many of the collected animals as possible. Invite a science teacher or some person in the community to check the pupils' identification and discuss the kinds of foods these animals eat.
5. Discuss good conservation practices that pupils should follow when collecting food plants. (Either a sharp knife or pruning clippers should be used when cutting the stems and branches of plants. A small cut or bruise is less serious than a jagged or large one. Small cuts and bruises are less likely to become infected and they heal faster. Encourage a discussion based on the experiences of the children with their own cuts and bruises.)
6. Compare what the children's constant-temperature pet mammals and birds must have to live with the variable-temperature animals studied. (The requirements for their pet animals were *air, food, water,* and *heat.* They will be certain that the variable-temperature animals that they have cared for also must have *food* and *heat.* They may not be so certain that these animals also use *air* and *water* because they may have never seen these animals drink water as they have seen other animals do. They may be unable to see or to hear these animals breathe.)

Experimenting to determine the needs of both constant- and variable-temperature animals

Ask the children to watch snails and fish feeding. (Aquatic snails eat food that is covered with water. Fish gulp both food and water.) Ask them to recall the kinds of food the land insects and spiders ate. (Some ate plants and some ate other animals.) Help them to discover that both plant and animal food contain water and to understand that animals obtain water from eating either kind of food.

Have the children crush some green leaves on a piece of paper or on the chalkboard. Have them see the water spot this makes and watch it disappear as the water evaporates into the air.

Dry the insides of two glass jars. Have the children place some fresh leaves in one jar. They are to use the other as a control. Cover both jars very tightly and place them in a sunny window. Within a few hours, the children will see water droplets forming on the inside of the jar containing the leaves. There should be no water droplets in the control jar. Ask the class from where the water must have come. (From the green leaves.) Talk about some of the experiences they have had that make them believe that plants contain water. (House plants are watered frequently. Bouquets of cut flowers are placed in water. Food plants for our animals are placed in water to keep them fresh. A crushed green leaf makes a water spot. People water gardens during hot, dry weather.)

The bodies of animals also contain water. The class has had a number of experiences with this fact. They have seen the wet stains made by insects that fly against the windshields of automobiles, the wet spots left when grasshoppers and flies are killed. Children know that their own bodies contain water because they drink water and other liquids; they perspire when they are very warm; and there is water in their tears and urine.

Observe the breathing of the snails and fish in the aquarium. Look for the gills on fish and the small hole on the bottom of a snail's foot just below its head. This hole can be seen when the snail is moving. Watch the gill slits of the fish and the mouth in the bottom of the snail's foot open and close. Fish and snails get their air by means of gills and openings in their bodies. They do not have lungs but they do have ways of obtaining air from the water in which they live.

The discussion about how fish and snails get air will be more convincing to the class if they know that water contains air. Children can do several simple experiments to help them understand that air mixes with water. Fill a glass tumbler with hot water. Let the water stand for a few minutes. Notice the air bubbles that collect on the inside of the tumbler.

Boil some water and watch the bubbles that rise as the water heats.

Fill a quart jar full of boiling water and seal this jar. Pour a second quart jar full of tap water and seal it. When the boiled water reaches room temperature, let the children taste the water from each jar. (Be sure to save part of the water in each jar for the next experiment.) Each child will need two paper cups to hold his samples of water. Tell the children to draw a big X on the cup in which they want their sample of boiled water to be placed. Appoint one child to distribute a sample of the tap water in the other cup. Caution the children who are to distribute the boiled water to dip it out with a spoon and to lower the spoonful of water into the cup before emptying it. (This precaution is taken to avoid mixing air with the water when it is being transferred from the jar to the cup.) Ask the children to taste the two samples of water. Which one tastes better? (The boiled water will have a flat taste. The children will probably say that the boiled water does not taste as good as the water from the tap.) Have them recall what they saw happening when the water was boiling. (They saw air bubbles rising to the top of the water.) How can we find out whether it is air that makes the tap water taste "better"? (By putting air back into boiled water.) Encourage the class to plan a way to mix air with boiled water. Try their suggestions even though they differ from the method used in the following experiment.

Set a pan on the floor and have one child pour the boiled water from the jar into the pan and from the pan back into the jar. Repeat this five or six times. While the experiment is going on, ask the children to name the substance that is all around them, all around the jar, all around the pan, and between the pan and the jar. Have the class express their opinion as to whether this may be one way to mix air with boiled water.

If the children have an aquarium with water insects in it, have them watch the insects come to the top of the water and shove the end of their bodies (abdomens) above the surface. Call their attention to the little bubble of air clinging to the end of the insect's abdomen. The bubble can be seen easily as the insect swims down to the bottom of the aquarium. If the class watches very carefully, they can see the bubble of air protruding from the end of the insect's abdomen get smaller and smaller until it finally disappears. A few seconds after this happens, the insect will return to the surface of the water for more air.

Turtles, some salamanders, frogs, and toads have lungs, but they take in air more slowly and in much smaller amounts than other lung-breathing animals. Because these animals breathe so slowly and take in so little air, the class may not be able to see them breathe unless they watch very carefully and know how to tell whether the animals are breathing. Put a frog or turtle in a pan of water so deep that the animal must swim to reach the surface. Let the children observe what these animals do when they rise to the top of the water. The animals may push their heads out of water for a few seconds before they swim under water again, or they may protrude their heads just far enough to get their nostrils above the surface. If the class watches very closely, they may see the nostrils of a turtle open as it raises its head above water and close before it submerges. Also have the children watch the movement of a toad's or frog's throat as it pulls in air (inhales) and of its sides (diaphragm) as it pushes air out (exhales). These animals also get air through the pores in their skin. This is why it is so important to keep the home in which they live very moist. If their skin gets too dry, the pores close and the animal cannot get as much air as it needs.

The spiders and the land insects get their air through small openings on the sides of their bodies (thorax and abdomens). These openings can be seen very easily on each segment of the grasshopper's body. Watch a grasshopper's body move up and down as it inhales and exhales air.

Most children, even in the early primary grades, believe that houseflies are pests, and many children have helped their parents kill them with fly swatters and sprays. Your class may have developed similar attitudes toward crickets and grasshoppers. Let the class decide what kind of insect pest they want to use in some experiments to find out whether insects breathe air. Make sure that the children regard the animals used in the following experiments as pests and that they understand that these animals do not feel pain as humans do. Select two insect pests of the same kind. Place one insect and some of its food in a half pint jar; place the second insect and its food in an identical jar.

Fig. 12.4 Microscopes help students study insects. *Courtesy Marion B. Betar.*

Screw the lid very tightly on one of the jars and cover the other with a piece of cheesecloth. Help the children understand that the first jar is airtight but that air circulates through the cheesecloth on the control jar. If houseflies are used in this experiment, in three or four hours the class should be able to observe a difference between the activity of the fly in the experimental jar and the one in the control jar. The fly in the experimental jar should be less active than the one in the control jar. Within 24 hours, the fly in the experimental jar should be dead, but the fly in the control jar should be alive. Raise these questions: Why didn't the fly die when the experimental jar was first sealed? What do you think might happen if the fly were placed in a smaller sealed container? Try this experiment with crickets or grasshoppers and find out whether they also breathe air.

The children's experiences with insects dying in covered jars may cause them to wonder about the air supply in their covered aquarium. If there is an insufficient supply of air in the aquarium water, the snails will move to the bottom of the aquarium and withdraw into their shells and the fish will stay near the surface of the water. Should the aquarium animals act like this for several hours, have the children try adding more air to the water. They can use several procedures: (1) siphon or dip the water out of the aquarium and aerate it as was done in the experiment with boiled water; (2) beat air into the water with an egg beater; (3) pump air into the water with a bicycle pump. After aerating the water, the class should try to find out why the animals were not getting the air they needed from the water. There might be several reasons: (1) the aquarium may have too many animals; (2) it may have too few water plants; (3) the water plants may not be growing; (4) there may be too many dead leaves on the plants; (5) the children may be giving the water animals more food than they can eat.

Each of these possible causes should be checked. Remind the class of the rule, "not more than an inch of fish to a gallon of water." If there are too many fish, one of the children might stock an aquarium at home for these excess animals. Have the class examine the water plants. Perhaps the fish and snails are eating them. If this is true, more plants should be added and probably some of the snails should be removed. If the plants are growing, the class should be able to see air bubbles on the edges of the leaves and lighter green leaves on the ends of the plants. Ask the children to look for dead plant leaves on the plants and leftover food on the bottom of the aquarium. Cut off any dead leaves and remove the food debris from the top of the sand. This debris can be picked up with a long spoon or forceps. Very young children may not be ready for the explanation of why growing plants are necessary to maintain the oxygen requirements of the animals in the aquarium, but many children in the intermediate grades are. If your class wants to know why more plants are needed in the aquarium or why dead leaves and leftover food should be removed, give the children the experiences suggested in Chap. 13, Inquiry 1.

If the children have not previously observed that when they touch and handle animals some feel cold and others warm, have them compare the skin temperatures of animals. Have the children feel the bodies of several of the different kinds of variable-temperature animals that they are caring for in the classroom. Such animals as grasshoppers, crickets, and caterpillars, which do not have spines, bristles, or hair, may feel like cool wax paper. Ask the class to decide which feels warmer—their skin or the skin of one of these variable-temperature animals. This difference can be detected more readily by placing one hand on the back of their neck and the other on the skin of the variable-temperature animal. Have the class repeat this using a frog, toad, or salamander. The moist skin of the salamander will feel even colder than did the insect's skin.

As the temperature of the air or water falls nearer and nearer to 32°F, these animals become less and less active. As the temperature rises, the activity of the animals increases. Find out whether the children ever noticed how sluggish bumblebees are on a clear, cool morning. Maybe they have helped their mothers pick garden flowers in the early morning when the plants were covered with dew. If any of the children have had this experience, they may have seen beetles, bees, and ants that did not even try to escape when they picked the flowers. Sometimes, these variable-temperature animals are so quiet and their color so nearly matches the leaves and flowers, that they are not even noticed until they have been brought into the house where they get warm enough to become active again.

Variable-temperature animals get much of this heat energy from the sun. However, they do get some energy from the food they eat. When variable-temperature animals do not have enough heat energy to move about, they stop feeding.

Place an equal number of houseflies in separate glass jars. Cover the jars with cheesecloth. Be sure the class understands that air can circulate through the cloth. Place one jar in a pan and pack crushed ice around it. Use the second jar as a control; it will remain the same temperature as the room. When the jar is cold, have the children observe the differences in the activity of the flies in the two jars. The flies will be much less active in the experimental jar. Repeat this same experiment with grasshoppers and crickets.

If the children collected caterpillars, have them choose two caterpillars of the same kind and observe what change occurs when one of them is colder than the other. Place each of the caterpillars and its food plants in separate glass jars. Wait until the caterpillars begin to feed before continuing with this experiment. As soon as they are feeding, place one of the jars in a pan and pack ice around the jar. When the temperature drops low enough in the experimental jar, the caterpillar in it will stop feeding. Repeat this several times. If the same caterpillars are to be used, wait until both are feeding before repeating the experiment.

Help the children summarize what they learned about the things variable-temperature animals need to keep alive. Have them discuss and compare their findings pertaining to constant-temperature animals with their findings about variable-temperature animals. Questions similar to the following might be used to stimulate this summarizing discussion: "What did you see that makes you believe animals eat food?" "How many ways did you observe animals getting water?" "What experiment did we do to find out whether animals breathe air?" "How do water animals get air?" "How do (land) insects get air?" "How do spiders get air?" "Which animals can take in air through their skins?" "What experiment did we do to show that variable-temperature animals must have heat?"

"Which four things have we learned that all animals must have?"

What must green plants have to live?

1. Discuss the concepts the children have formed about green plants. Most pupils know that green plants must have *heat and water.* However, they may have misconceptions about *food and air.* Select your vocabulary carefully so that you do not reinforce any misconceptions the pupils already have or cause them to develop new misconceptions. Be on the alert for the following common *misconceptions: Green plants get their food from the soil. Green plants do not require air. They make air for people and animals.*

2. *Experiment to find out whether minerals from the soil and water are necessary for green plant growth.* Dry lima or kidney bean seeds are good seeds to select for this purpose. *Examine* the bean seeds. *Feel* how hard they are. Soak some of the seeds in water overnight. *Compare* these wet seeds with dry ones. Open a few seeds to find out what is inside. *Observe* the tiny plant which is attached to the two halves of the bean seed. Also *observe* that most of the inside of each of the halves is filled with a yellowish-white substance. Have the pupils *guess* what this substance may be. (Prediction: This is food that will be used by the tiny plant when it germinates and develops into a young plant.) Make paper patterns of equal numbers of soaked and dry seeds. Use these seeds in the following experiment. Obtain 6 identical glass jars that have covers. Cut 6 pieces of paper towel which are all the same size. Wet 3 of the pieces and put one of each in a glass jar. Put the other 3 pieces of dry towel in separate jars. Place several of the wet seeds on the wet paper towels. Place the same number of dry seeds on the dry paper towels. Place the covers on the 6 jars. Put the jars in a warm dark place. Check the seeds daily to discover whether the seeds are germinating. When the wet bean seeds have germinated and grown to a height of 3 inches, bring the jars into the classroom. Compare the size of the seeds with their paper patterns. Which ones change size? (The soaked ones that germinated.) Encourage the class to *deduce* what has happened to cause this change in size. Repeat the previous experiment using different seeds. Popcorn, dry corn, or pea seeds could be used. Ask the children to predict what they think may happen to the dry and the soaked seeds. Record their predictions and have the pupils check them at the end of the experiment.

3. *Experiment to find out whether plants must have heat for growth.* Place soaked bean seeds in two jars and dry seeds in two others. Vary the experiment by placing one jar containing wet seeds and one containing dry seeds in the freezing compartment of the refrigerator. Place the remaining jars in a warm dark place. Have the pupils *predict* what they think will happen in this experiment. *Check their predictions with their findings.* The unfrozen soaked seeds will have germinated. The soaked seeds, which were frozen, will not have germinated. If there is any color change in the dry seeds, they also may have frozen. Soak overnight the dry seeds that were frozen to find out whether they will germinate. Some, perhaps all, will germinate. See Chap. 45, Inquiry 5. Wrap in transparent food wrap a branch of a fleshy plant, such as coleus or geranium, and place it in the freezing compartment of the refrigerator. Wrap a second branch, which is similar in size, and leave it on a table in the classroom. The following day *observe and compare* any changes that may have occurred. Discuss some of the experiences the pupils may have had with the freezing of garden and vegetable plants.

4. *Experiment to discover whether air is necessary for plant growth.* The fact that green plants grown in sunlight, make their own food and release oxygen as a by-product of food making is so much emphasized that children develop the misconception that oxygen is not necessary for carrying on life processes. Actually, both plants and animals use oxygen, and different kinds of plants and animals have different methods of obtaining it. Although one could do experiments similar to the following with mature plants, they would be more complicated to perform. Therefore, use plants that are just beginning their growth. Until a green plant has green leaves, it must obtain its oxygen requirements from the air present in the soil. Even mature plants obtain oxygen from the soil if they are grown in darkness. If the children set up and observe the

results of experiments like these, it will help them realize that green plants do require air for growth processes.

Soak at least a half dozen bean seeds overnight. Cut four pieces of nonporous paper (plastic wrap, cellophane, or wax paper) into pieces about four inches wide and six inches long. Cut small air holes in *two* of the pieces of paper. Make a one-inch plait in the center of each piece of paper to allow for expansion as the young plant grows. Lay a piece of moist cotton on each piece of paper and a seed on each piece of cotton. Wrap and seal the edges of each of the four seed packages. Two of the seeds will be in separate airtight wrappings and two of them will not. Place two more bean seeds on moist pieces of cotton, without any wrappings. This part of the experiment will help the children find out whether the wrappings on the other four seeds have any effect on their growth. Put all six in separate glass jars. Screw the lids tightly on the two jars containing the seeds with the airtight wrappings. Use lids with air holes punched in them on the four jars containing the other seeds. Put all six jars in a warm, dark place. Have the class observe the jars of seeds daily in order to observe any changes. Water should be added whenever beads of moisture cannot be seen in the jars or inside the wrappings with air holes in them. Water can be inserted through the air holes of the two paper wrappings with a medicine dropper. It may take as long as six days before convincing results can be obtained. These are some of the things that the children should observe:

1. All the seeds may not germinate. (The children may want to find out whether all seeds usually germinate.)
2. All the seeds that germinate will continue to grow for several days. (Point out that the plants are obtaining their air during this period from the water, the cotton, and the space between the seed and the wrappings.) Later, growth will be retarded, the growing tip will turn dark, and the seedling will die.
3. The seedlings that have been given a constant supply of air will continue to grow unless the cotton has been kept too moist. Molds will develop if the seedlings have been given too much water.
4. The seedlings in the airtight wrappings will be spindling and will not grow after several days have passed. Mold will probably develop and the seedlings will decay.
5. In the wrappings with air holes the seedlings (unless they have been kept too moist) may continue to grow and burst through their wrappings.
6. The seedlings that are not wrapped will grow straighter than the seedlings in the wrappings with air holes.

Try this same experiment with two onions placed on moist cotton. Put one onion and the moist cotton in a jar and cover it with a lid that has holes punched in it. Place the second onion and moist cotton in a very small plastic bag. Fold and seal the bag so that the onion is in a very small airtight space and place it in a jar and seal it. Remind the children to water the cotton in the jar that has air holes in the lid.

Have the class set up a third experiment using potato buds instead of seeds. Cut a lengthwise slice, about half an inch thick, from one side of the potato that has several eyes or buds on it. By cutting between the buds on this large slice, several smaller pieces can be obtained. Have the children plan a setup that will help them discover whether potato buds need air to grow. They may want to try a different procedure from the ones used in the experiments with the bean seeds and onions. Question the class regarding the source from which potato buds obtain air, water, food, and heat.

In the experiments with the onions and the potatoes, the children will obtain results that are similar to the ones they obtained in the previous experiment. Both onions will germinate, unless mold develops. The onion and the potato buds in the airtight wrappings will grow for several days and then growth will slow down and stop. (The onion and potato plants will take much longer to germinate than the bean seeds did—it may take as long as two weeks.)

5. *Summarize the pupils' findings regarding the common conditions necessary for plants and animals to live.* Check to find out whether any misconceptions remain. If misconceptions have not been clarified, repeat some of the experiments to correct them.

Chapter Thirteen

Plant and Animal Interrelationships

INQUIRIES

1. Why are green plants necessary in a community of living things? What kind of food is manufactured and stored by green plants? Where do green plants manufacture food? Is sunlight necessary for the manufacture of foods? What do green leaves release as a waste product of food making? What gas is used by plants in the food-making process? How do plants and animals release the energy stored in foods? How do they utilize the carbohydrate starch as an energy food?

2. Why are fungi (nongreen plants) essential in a community of living things?

3. Why are animals that eat plants essential in a community of living things?

4. Why are animals that eat other animals essential in a community of living things?

5. What are the interrelationships in a community of living things? How does man sometimes upset them? What problems has man created in these communities? What methods are being used to restore them?

1. Why are green plants necessary in a community of living things?

Discuss why green plants are important in a community of living things. The class may know that people and other kinds of animals obtain much of their food directly from green plants. Help them to understand that all their food comes either *directly* or *indirectly* from green plants. They may know that people and other animals use this food to carry on such life processes as growth, reproduction, and cell building. They may not know, however, that both green plants, which contain chlorophyll, and fungi, which do not contain chlorophyll, utilize this same kind of food to carry on their life processes. Be sure the children understand that green plants manufacture this food from the elements present in the air, water, and soil and that they then utilize it in their own life processes. Help them to understand that green plants, because they can manufacture food, are the only living things that do not depend upon other living things for food.

Also teach children that green plants in this process of food making *(photosynthesis)* release oxygen as a waste product, and that this oxygen, and the food manufactured by green plants, is necessary in a balanced community of living things.

Pupils can expand their concepts about the contributions of green plants to a plant and animal community by using experiences similar to those that follow:

What Kind of Food is Manufactured and Stored by Green Plants? Ask the children to use their science books to find the names of the three classes of foods stored by green plants. (They are *carbohydrates, fats,* and *proteins.*) Help them to understand that the carbohydrates consist of starches and sugars.

From food charts similar to Table 13.1 have the children make lists of plant foods with high percentages of fat, protein, and carbohydrates. They will discover that the carbohydrate starch is stored in the potato tuber; in the parsnip root; and in corn, wheat, and rice seeds. In peanut, soya bean, avocado, cotton, and corn plants, fats and proteins are stored in the seeds. In beet, sugar cane, fruit trees and berry bushes, sugars are stored in the roots, stems, and fruits.

Have the children find out why both plants and animals must have each class of food. They should learn from their reading that carbohydrates and fats are called *energy foods,* because they provide the heat energy necessary for plants and animals to carry on such life processes as growth, reproduction, and cell building. Proteins are often called *cell—or body—building foods* because both plants and animals must have them for building protoplasm. They will discover through their reading that minerals and vitamins also are essential to both plants and animals for building new cells and carrying on life processes.

Be careful that pupils do not form the *misconception* that *plants store carbohydrates, fats, and proteins for use by people, other animals, and fungi.* Food is stored only because the plant manufactures an excess. *Nor do plants store food in their seeds and fruits for the baby plants* (embryos). Different kinds of seeds do contain food that is used by the baby plants when the seeds germinate, but no living things, except man, purposefully plan ways to improve their living conditions or to provide for their young. Excess food is stored in animal tissues in the

Table 13.1
PERCENTAGE OF CARBOHYDRATES, FATS, AND PROTEINS FOUND IN THE DIFFERENTS PARTS OF GREEN PLANTS USED FOR FOOD

Food	Carbohydrate	Fat	Protein
Apples	14.2	0.5	0.4
Bananas	22.0	0.6	1.3
Beans, lima	22.0	0.7	7.1
Brazil nuts	7.0	66.8	7.0
Butternuts	3.5	27.9	61.2
Cabbage	5.6	0.3	1.6
Carrots	9.3	0.4	1.1
Corn, green canned	19.0	1.2	2.8
Grapes	19.2	1.6	1.3
Onions, fresh	9.9	0.3	1.6
Oranges	11.6	0.2	0.8
Peaches	9.4	0.1	0.7
Peanuts	24.4	38.6	25.8
Peas, green	16.9	0.5	7.0
Pineapple	9.7	0.3	0.4
Potatoes, white raw	18.4	0.1	2.2
Walnuts, California	13.0	64.4	18.4
Watermelons	6.7	0.2	0.4
Lettuce	2.9	0.3	1.2
Cucumbers	3.1	0.2	0.8
Wheat (flour) bread, white homemade	53.3	1.6	9.1
Whole wheat	49.7	0.9	9.7

form of fat and a starchlike substance called *glycogen.* Many kinds of plants and animals have specialized storage tissues. Lower plants, such as the fungi, and one-celled animals, such as the protozoa, lack specialized storage tissues.

Explain to the children that chemists use tests to detect the presence of fat, protein, and carbohydrates in both plant and animal foods. Ask the class to find some of these tests in their science books. These simple food tests can be found in Chap. 45, Inquiry 6.

In What Part of a Green Plant Is Food Manufactured? Does It Need Sunlight to Manufacture Food? The children may have read that green plants manufacture food in their leaves. They should be encouraged to test green leaves for starch, sugar, fat, and protein. Chlorophyll is easily removed from geranium leaves. In order to observe any color change that these tests may show, the green color (chlorophyll) must be removed from the leaf before it is tested. Boil the green leaf for several minutes. Remove it from the water. Soak the leaf for a few minutes in alcohol. Remove it when the chlorophyll has dissolved in the alcohol. After the leaf has been washed and dried, divide it into four pieces and test it for starch, sugar, fat, and protein. The children should discover that green leaves contain starch. They also should test more than one kind of green leaf. Encourage them to test and compare the parts of leaves that have white markings on them with the green part of the leaf, such as coleus leaves.

Help pupils plan an experiment to check the statement that green plants manufacture food in the presence of sunlight. Cover one leaf or a part of one leaf with black paper to exclude the light for several days. Using the iodine test, check for starch the part that was without sunlight and the part that had sunlight. Be sure that the children remember to remove the chlorophyll before they make the iodine test. Ask the class to check their results with what authorities have discovered.

What do Green Leaves Release as a Waste Product of Food Making? What Gas Is Used by Plants in the Food-Making Process? Plan and conduct some experiments with lima bean seedlings or rooted philodendron slips, both of which grow rapidly in water, to find out whether green plants use carbon dioxide and release oxygen in the process of food making. Give the children the opportunity to state the problem they are trying to solve and to organize their data. This is an example of how one class attacked this problem:

> Carbon Dioxide—Green Plants—Oxygen
>
> *Statement of Problem.* What gas do green plants use for food making? What gas do they release as a waste product during this process?

See Table 13.2 for directions. Sometime during the two week waiting period, have the children make a record of the time a splinter will burn in a wide-mouthed quart jar of air, in a quart jar of carbon dioxide, and in a quart jar of the gas that remains after a candle has removed the oxygen necessary to support combustion. The pupils also should become skillful in the method of quickly inserting the burning splinter into a jar as soon as its lid is removed. They need to know how to do this before they use the burning splinter test on the experimental jars.

During the discussion of the experiments, help the children understand that green plants use carbon dioxide, water, and sunlight to manufacture food and that they release oxygen, a waste product of food making. Help the children to recall that the carbohydrates contain carbon, oxygen, and hydrogen. Find out whether they know where the green plants, that manufactured food in the experiments, obtained these elements. (Carbon is present in carbon dioxide, CO_2; hydrogen is present in water, H_2O; and oxygen is present in both carbon dioxide and water.)

How do Plants and Animals Release the Energy Stored in Foods? How do they Utilize the Carbohydrate, Starch, as an Energy Food? Burn small samples of food so that the class will realize that foods are fuels which contain heat energy. Try heating water in a teaspoon with the heat energy released when foods are burned. Plan an experiment to prove that burning foods stop burning (oxidizing) when there is not enough oxygen present to support combustion. Also plan another experiment, using the limewater test (Inquiry 6, Chap. 10), to learn that oxidizing foods give off carbon dioxide as a waste product. Be sure the class understands that these experiments with the burning of foods are experiences with rapid oxidation.

Plants and animals use oxygen from the air to oxidize foods. Even in this slow process of

Table 13.2

DATA ON GASES USED AND RELEASED IN THE FOOD-MAKING PROCESS BY PLANTS

Large-mouthed Quart Jars with Screw-top Lids	Contents of Jar	Procedures*	Time and Location	Class Predictions	Results	
					Burning Splinter Test for Oxygen	Iodine Test for Starch
Jars 1, 4	One plant in a small container of water; candle	To remove the oxygen which supports combustion, ignite the candles in jars 1, 2, and 3 and seal them with the screw-top lids.	2 weeks in sunshine	Enough *oxygen* should be present in jars 1 and 4 to support combustion; *starch* should be present in leaves.		
Jars 2, 5	No plant; a small container of water; candle (a control)		2 weeks in sunshine	Not enough *oxygen* should be present in jars 2 and 5 to support combustion.		
Jars 3, 6	One plant in a small container of water; candle	Fill jars 4, 5, and 6 with carbon dioxide. (See Inquiry 2, Chap. 9.)	2 weeks in dark (a control)	Not enough *oxygen* should be present in jars 3 and 6 to support combustion; *starch* should not be present in leaves.		

* Six duplicate jars should be set up to make certain that the results are not accidental.

oxidation (without flame), heat energy and carbon dioxide are released. Have the class check their body temperatures. Have them test with lime-water the gases they exhale in order to realize that oxidation is taking place in their bodies. Green plants also use oxygen from the air to oxidize the foods which they manufacture and store.

Put some cornstarch in a beaker and mix it with water. Have the children mix some table sugar and water in a second beaker and squeeze some lemon or orange juice (fruit sugar) in a third beaker. Compare the three mixtures. Note how milky, or cloudy, the cornstarch mixture looks. Have a few children taste each of them and then pour the mixtures through separate filter papers. Observe the filtered liquids. The starch mixture will be clear. Have the tasters taste the three filtered liquids. (The tastes of the table sugar mixture and the fruit sugar mixture will not have changed, because their molecules were small enough to pass through the pores in filter paper. The sugar molecules are soluble. The filtered starch mixture will look and taste differently. Starch is not soluble in water, and its molecules are too large to pass through the pores in filter paper.) Test with iodine samples of the starch mixture before and after filtering and explain the results.

Have one of the children break an uncooked egg so that the class can see the membrane inside the shell. This thin membrane separates the eggshell from the egg white. If the children are careful, they may be able to remove a piece of the membrane that surrounds the fleshy leaves in an onion bulb. The cells and tissues of both plants and animals are surrounded by membranes similar to the egg and onion membranes. Let the class compare the size of the pores in these membranes with the pores in filter paper. They will need to use the school microprojector or a magnifying glass to make this comparison. Because the pores in plant and animal membranes are much smaller than those in filter paper, neither starch nor table sugar molecules can pass through them.

Test equal amounts of the starch, table sugar, and lemon or orange juice mixtures for fruit sugar. (The lemon or orange juice will show considerable color change because it contains much fruit sugar. The table sugar solution may change from blue to green or yellow-green if it contains a little fruit sugar. The starch mixture may be pale blue, but this is caused by dilution and is not a real color change. No color change indicates that no fruit sugar is present in starch.)

Heat the remainder of the three liquids. After the liquids have simmered for a couple of minutes, remove them from the heat. Note that the starch solution is now transparent but the two sugar solutions appear much the same. Test samples from each of these cooked liquids for the presence of fruit sugar. Compare the amounts of fruit sugar present before and after the sugar and starch mixtures were heated. Ask the children what happens to table sugar and starch when they are heated. (A little of the starch mixture changes into fruit sugar. There also is more fruit sugar in the solution of table sugar after it is heated.) Which liquid can be broken down more readily by heat—the starch or the table sugar? Some of the heat energy released when food is oxidized by plants and animals is used for breaking down the larger food molecules (starch and table sugar) into smaller molecules (fruit sugar). However, it would be a very slow process if plants and animals had to depend entirely upon heat energy to change food into the soluble fruit-sugar form that can pass through plant and animal membranes. Help the children develop this concept by comparing the high temperatures which they used to heat the starch and sugar liquids with the temperatures of animals and people. (The liquids were heated to boiling, 212°F, at sea level.) Compare the body temperatures of humans and green plants. The class can actually measure the temperature of a growing potato, carrot, or any large vegetable or fruit by making a hole in it and inserting a thermometer. (They will find that the temperature of vegetables and fruit is about the same as the air or ground temperature.)

The bodies of both plants and animals contain chemicals called *enzymes* that help to break large food molecules, such as starch, into small molecules, such as the fruit-sugar molecule. Hydrochloric acid, like the enzymes in living things, helps to change starch into fruit sugar. Set up this experiment and observe the change that occurs. Divide the remainder of the cooked starch solution into two parts and place each part in a separate beaker. One beaker of starch is to be used as a control. Add five or six drops of concentrated hydrochloric acid to the cooked starch in one of the beakers. Stir the acid into the mixture. Heat both beakers for several minutes. Take samples from each of the beakers and test them for the presence of fruit sugar. Which sample contained more fruit sugar? (The sample taken from the beaker to which the hydrochloric acid was added.) What do the results of these experiments show? (That starch molecules are too large to pass through filter paper. That starch can be changed into fruit sugar by heat and by an acid that acts like an enzyme.)

Help the class apply the experiences they have had in changing starch into fruit sugar to the changes that living things must produce in foods containing starch before they can use them for energy.

2. Why are fungi (nongreen plants) essential in a well balanced community of living things?

Ask the children to name plants which they think are fungi (lack chlorophyll). They will probably name such fungi as toadstools, mushrooms, and puffballs. The emphasis in this problem is upon the importance of fungi in a community of living things. Fungi release the minerals present in dead plants and animals. Help the children develop this concept by reading about such valuable fungi as the yeasts and molds that are used in the processing of cheese, the molds that are used in the production of such drugs as penicillin, aureomycin, streptomycin, and terramycin, the nitrogen-fixing bacteria that live in the root nodules of such plants as peas, beans, and clover (legumes), and the bacteria that decompose dead plants and animals into gases, liquids, and solids.

In Inquiry 1 (pages 150–51), the children learned that plants manufacture food from the elements in carbon dioxide, water, and soil. The tissues of both plants and animals can be changed by rapid oxidation (burning) into carbon dioxide, water, and ash (a carbon mixture). The reason animal tissue changes to these chemicals is that animals eat plants or eat other animals that live on plants. Have the children collect samples of plant and animal foods and burn them to find out whether rapid oxidation releases carbon dioxide, water, and ash. Place a small amount of the food to be oxidized in a test tube and hold it in a slanting position over the hot flame of an alcohol lamp. Warn the child doing the experiment to move the test tube back and forth through the flame until the test tube is warm. When the food begins to oxidize and smoke rises out of the tube, have the class observe the moisture that collects at the top of the tube. As oxidation continues, more and more water droplets will collect. Test for the release of carbon dioxide by holding a quarter of a teaspoonful of limewater near the lower edge of the top of the test tube. If the limewater turns milky, the children will know that carbon dioxide has been released from the plant and animal tissue. When the ash remaining in the test tube is cool, examine this carbon mixture. Guess what elements other than carbon may be present in this ash. Have several children look in reference books for the minerals contained in food.

Experiments similar to the following will help children form the concept that some kinds of molds and bacteria (fungi) break down plant and animal tissues into carbon dioxide, water, and the minerals of which they are composed.

Have one child pour equal amounts of limewater (enough to cover the bottom of the jars) into two glass jars. Let two other children cut two squares from wire mesh screening. These squares should be small enough to fit inside the jars in a horizontal position. Lay a piece of moist bread on *one* of the squares. Tie pieces of thread on each corner of the two squares. Suspend a square inside each of the glass jars containing the limewater. The squares can be held in position by hanging the loose ends of the thread on the outside of the jars and fastening them in place with rubber bands. Screw the lids on the jars very tightly and leave the jars in a dark, warm place for several days. At the end of this period of time, observe whether any changes have occurred inside the jars. (Mold probably will have developed on the bread; the limewater will probably look milky.) If the children observe carefully, they will see a small, flakelike precipitate on the top of the limewater. There will be a little of this precipitate in the control jar in which there was no bread. Ask the children why there was some precipitate in the control jar. (The space betwen the limewater and the top of the jar was filled with air. Air contains a small amount of carbon dioxide.)

Place some moist soil in a metal coffee can; lay a piece of moist bread on the top of the soil. Cover the can tightly and leave it in a warm place for at least a week. At the end of this time, observe how thickly the mold has grown on the bread. Take two needles and tear the bread apart. Notice how much thinner the bread has become. Examine the bottom of the bread. Has the mold grown through it? If the bread is left in the can long enough, it will not look like bread. Put the cover back on the can and try it. Eventually the children will be able to take a spoon and stir the mold into the soil until they will not be able to tell which part is bread, mold, or soil. The mold released the gases, liquids, and minerals present in the bread, and these substances were returned to the air and the soil.

Try this experiment with a raw squash, pumpkin, or tomato. Cut the fruit in half, count the number of seeds in one portion, and estimate the number of seeds in the whole. Place a piece of the fruit, with its seeds attached, on some moist soil in the bottom of a can. Cover the can and put it in a warm place. Every day, for a week or ten days, examine the changes that are occurring in the fruit. Molds will slowly change this fruit and its seeds into a soft, watery mass. Be sure that the class realizes that the molds are destroying both the food stored in the fleshy covering around the seeds and the seeds that might have grown into plants.

In the experiment with the fruit, the children estimated the number of seeds it contained. Ask the class to imagine what would happen in a community of living things if each of the seeds of this fruit developed into a mature plant. (The plants would become so crowded that only a few of them would be able to obtain the raw materials needed for making food. This community would be upset by the thousands of green plants needing more raw materials than were available.) Fungi such as molds are essential in any plant and animal community because they help to maintain an equilibrium between the number of living things that the community can support.

If possible, take a field trip to the woods or to a compost pile in one of the gardens in your community. Look for evidences of decay on the dead plants in the woods or compost pile. Try to find a branch or a log that has partially decayed. Bring samples of these decaying plants back to the classroom and examine them with a magnifying glass or with the microprojector.

3. Why are animals that eat plants essential in a community of living things?

Discuss what would happen if there were no animals that ate plants in a community of living things. These points can be developed in the discussion: There would be more plants. The plants would be crowded and, as a result, there would not be enough living space, sunlight, minerals, water, and carbon dioxide for all. If they did not have enough of these basic materials, they would not be healthy.

Go to a garden and measure the space used by one plant. A corn, bean, pea, or other plant may be selected. Collect all the seed-bearing fruit from the one plant and count the number of seeds produced by it. Estimate how much space would be needed for all of these seeds to grow into healthy plants. Estimate or count the number of seeds in one milkweed pod, poppy seed case, cucumber, pumpkin, or apple. Ask the class to imagine all of these seeds growing into new plants.

Lead the discussion so that your children come to realize that green plants produce a great many young and that there are factors which limit the number that can mature in any area. Some of the children may have heard their parents use the adage: "There can be too much of a good thing." Animals that eat plants and fungi serve an important function in a community of living things; namely, they help to control the number of green plants that mature.

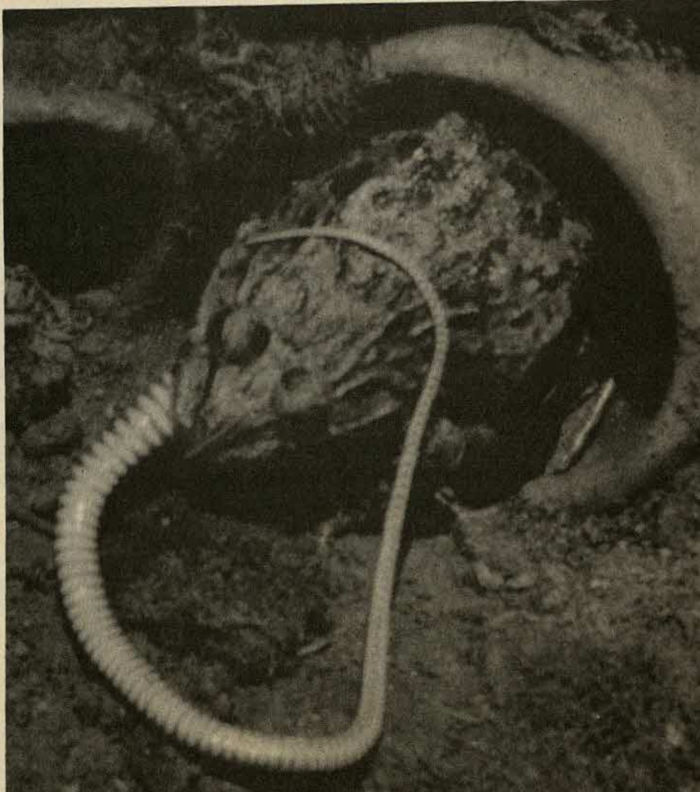
4. Why are animals that eat other animals essential in a community of living things?

Discuss what would happen if there were no animals that ate other animals in a community of living things. Some of these facts can be developed in the discussion: There would be more plant-eating animals. This larger number of animals that eat plants would decrease the number of green plants. People need the food that green plants manufacture. There might not be enough food for both people and plant-eating animals.

Open and estimate the number of eggs found in the egg cases of praying mantises and spiders. Estimate the number of eggs in the egg mass laid by one toad, frog, or fish. Estimate how much animal food would be needed for all of the animal eaters that could hatch from these eggs. What animals feed on toads, frogs, fish, praying mantises, and spiders? (Snakes eat toads and frogs; frogs, in turn, eat small snakes, as shown in Fig. 13.1. Fish feed upon the eggs and young of water animals. Big fish eat small fish, and sometimes they even eat their own offspring. Praying mantises feed upon spiders, Japanese beetles, and many kinds of insects; they also feed upon each other. Different kinds of birds feed upon all of these animals.) The children will soon realize that larger animals feed upon small ones, that some feed upon each other and frequently even upon their own kind, and that all of these help to keep the animal population under control.

5. What are the interrelationships in a community of living things? How does man sometimes upset them? What problems has man created in these

Fig. 13.1 A frog eating a snake.



communities? What methods are being used to restore them?

Trace the food chain and interrelationships that exist in a meadow community in which cows feed. The children will discover that green plants, fungi, people, and other animals are related and interrelated in a series such as this:

1. People get some of their carbohydrates, fats, and proteins from other animals (dairy and beef products from cattle). They get others directly from green plants.
2. Animals, such as cows, that eat plants get their carbohydrates, fats, and proteins from such green plants as alfalfa, clover, grass, corn, and ensilage (finely ground corn stalks that have fermented or aged in a silo).
3. Fungi use the food in the cells of either living or dead plants and animals.
4. Green plants, in the presence of sunlight, manufacture carbohydorates, fats, and proteins from carbon dioxide, water, and minerals.

Therefore, people, animals, and fungi must have green plants for food.

1. People, animals, fungi, and green plants use oxygen to oxidize their food for growth and energy.
2. Green plants give off oxygen as a by-product of food making.

Therefore, people, animals, and fungi also must have green plants for oxygen.

1. Green plants use carbon dioxide to manufacture food.
2. Green plants, fungi, people, and animals use oxygen. As a by-product of oxidation, they return carbon dioxide to the air.

Therefore, green plants must have the carbon dioxide released by *fungi, people and animals.*

1. Green plants use minerals to manufacture food.
2. Fungi decompose the food stored in the cells of plants and animals into the carbon dioxide, water, and minerals that green plants use to manufacture food.

Therefore, green plants must have fungi for the minerals *released by them.*

Help the children understand why man has produced so many problems for himself. Help the children to visualize what their region was like before it changed into a city, town, croplands, grazing lands, poultry farms, or forest preserves. Was their region covered with grasses, forests, swamps, or with a combination of two or more of these kinds of communities? The lowlands and highlands of the eastern and western coasts of the United States and Canada were covered with forests; the plains and highlands of the Middle West were covered with grasses and trees.

Have the class make a list of the many different kinds of plants and animals that formerly lived in their region. Be sure that their list contains some of the common plants and animals that are classified in a number of the different plant and animal phyla. Table 15.4 contains the classes of these living things and the kinds of habitats in which they live. Use this table as a check list to help the children broaden their concept of the variety of living things that lived in their region. Help the class understand the importance of each kind of plant and animal that belonged to this natural community. All the living things in this natural community were beneficial because each kind kept one or more kinds of other living things in control and provided some of the conditions that were essential for carrying on life processes.

Because man-made communities of living things lack this variety, man must introduce new kinds of controls. Man's communities are dominated mainly by a few kinds of plants, such as wheat, corn, vegetables, and fruits, or by a few animals, such as cattle, horses, hogs, and poultry. He classifies beneficial plants and animals as those kinds of living things that supply raw materials needed by the green plants he cultivates, the forests he plants or protects, and the food they provide for his domesticated animals. He classifies harmful plants and animals as those kinds of living things that he is not domesticating or is not protecting from other living things. Green plants that he does not sow in his croplands are called *weeds*. Fungi that feed on his plants and animals are called *diseases*. Wild animals that feed on his food crops or on his domesticated animals are called *pests*.

Man wants all his domesticated plants and animals and the trees in his forests to mature and to reproduce more and more of their kind. And he wants all of their young to grow up. When the raw materials in the soil become insufficient to supply the needs of his food crops, he replenishes the soil with fertilizers. If the natural water supply is insufficient for his crops, he irrigates the land and brings in water from other areas. If the land is too wet for the kinds of crops he wants to grow, he drains the land. If he wants to raise a kind of plant or animal that does not grow in his region, he brings it in from other countries.

Man has set up a new kind of community in his environment. At present, this man-made community lacks the built-in controls that exist in a natural community of living things. In his man-made communities, he must learn how to maintain a balance contrary to the natural ones that formerly existed in his biological environment.

Help the children to discuss and investigate some of the mistakes that man has made in learning how to live in a community of living things in which he has taken over some of the controls. These are some of the problems that children can read about and discuss:

1. Game laws that protect deer and cause a condition of overpopulation, which results in damage to forests.
2. Protecting plants by using chemical sprays, which endanger both bird and fish life. Many of these animals are dying because their food supply is poisoned by these sprays.
3. Man-made deserts that have resulted from overgrazing and overframing.
4. Overcutting of the forest lands that provided shelter and food for wild life.
5. Killing off such animals as passenger pigeons, whooping cranes, and buffalo.
6. Introducing from other countries plants and animals that either have no natural enemies or develop no immunities to the disease-causing organisms in this country.
7. Accidentally introducing new kinds of plants and animals that cause destruction to both domesticated plants and animals. (San Jose scale, Dutch elm tree blight, European corn borer, and so on.)

Following the discussion of some of the mistakes man has made in learning how to live in his biological environment, investigate some of the ways man is learning how to control communities of living things. Discuss some of the following kinds of controls that are being used:

1. Antibiotics : Some compounds produced by fungi, such as streptomycin and mycobacillin, are being used to control such diseases as wheat rust, cabbage wilt, root rots, and blights. Both of these drugs are produced by fungi and can be used to cure disease and build immunity to certain kinds of diseases caused by fungi. Some of these drugs—streptomycin is one—can be used to combat diseases in both plants and animals. The use of chemicals to prevent and cure plant and animal diseases is a new field in which much progress is being made. The children may be able to find several new chemicals in addition to the two that have been suggested.
2. Use of insects to combat enemies of food crops : One kind of lady bird beetle was brought from Australia to combat the cottony cushion scale that attacks citrus fruits. Ichneumon "wasps" were imported from England to control cabbage worms and wooly aphids (plant lice). Praying mantises were brought from the Orient to kill insects that injure shade trees.
3. The establishment of insectaries to feed and rear beneficial insects that feed on enemies of food crops : Because it is rarely possible to collect large quantities of beneficial insects to use as controls, many countries have established insectaries from which crop growers can buy these insects at a nominal cost whenever they are needed.
4. The collection of insects by the U. S. Department of Agriculture to distribute free of charge to farmers. The insects are used to feed on the enemies of food crops : In the fall, ladybird beetles become dormant. In places where they gather in huge, compact colonies, they can be collected economically and in large quantities.
5. Purchasing beneficial insects from tradesmen who grow them for a livelihood : For centuries, Chinese citrus growers have been buying predaceous ants to protect their trees from insect pests. The Chinese fruit growers place bamboo poles from tree to tree in their orchards to provide runways for these beneficial ants. In areas too cold for the ants to nest over the winter, the citrus growers buy these insects from tradesmen who earn their living by raising and selling these ants.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Green plants are necessary in a community of living things because they provide food and oxygen for other living things. Green plants are the only living things that can manufacture food from the elements in the air, water, and soil. As a waste product of photosynthesis, green plants release oxygen. Green plants produce carbohydrates, fats, and proteins. The leaves of plants produce food. Green plants use carbon dioxide from the air and release oxygen into the air. All living things need oxygen for releasing the energy contained in foods. In order to utilize the carbohydrates, living things must break down by heat energy and enzymes the large molecule into smaller molecules. The cells and tissues of living things are surrounded by membranes through which only small food molecules can pass.

2. Fungi obtain their food from other plants and animals. Fungi that cause rot or decay release the elements that are locked up in plant and animal tissues. These elements are released in the form of gases, liquids, and solids. Fungi that produce rot or decay in a community replace the carbon dioxide, water, and minerals that green plants take from the air, water, and soil. Fungi also help to maintain communities.

3. Animals that eat plants limit the number of green plants in a community of living things.

4. Animals that eat other animals reduce the number of animals in a community.

5. All living things in a plant and animal community tend to limit the number which survive. They also provide some of the conditions which are essential for carrying on life processes. Man has made a new kind of community in his biological environment in which he encourages only a few kinds of plants and animals to live. Man is learning to use some of the controls that formerly operated in a community of living things.

Chapter Fourteen

Plants and Animals Reproduce Their Own Kind

INQUIRIES

1. How do some kinds of animals reproduce their own kind?
2. How are human beings reproduced?
3. How do some kinds of plants reproduce their own kind?

1. How do some kinds of animals reproduce their own kind?

Discuss with your children the ways animals reproduce. They will suggest that some baby animals hatch from eggs. Help them to make a list of animals that lay eggs. Their list may include some of these animals.

SOME ANIMALS THAT LAY EGGS

Chickens
Ducks
Turkeys
Robins
Fish
Toads

Frogs
Snakes
Turtles
Grasshoppers
Crickets
Flies

Mosquitoes
Bees
Ants
Praying mantises
Spiders

It is important to provide opportunities for children to examine the eggs of some of these animals, to watch eggs being laid, to learn how the baby (embryo) develops in the egg, and to see the life cycle through which some animals pass between the time they hatch from the egg until they grow to look like their parents. Have the class look in their science books for information and for pictures about animals that produce eggs. Use a bulletin board with a table in front of it on which to display the pictures and books. Look for some of these eggs and bring them to class to display here. Discuss the reasons for not stealing birds' eggs from nests and for collecting only those eggs or broken shells that fall from the nest. Try to locate the eggs or egg cases of spiders, praying mantises, grasshoppers, crickets, mosquitoes, flies, ants, fish, toads, frogs, turtles, and so on. Information about where and when to look for the eggs of these animals can be found in reference books. The children should compare the eggs of one animal with those of other animals. Look for differences and likenesses in the eggs. Let them open the eggs to compare the materials in them.

Obtain some hens' eggs that are fertile and some that are not fertile. Open both kinds and look for something in the fertile eggs that is not in the others. Attached to the yolk of fertile eggs there is a small white film of material called a *germ spot* or *fertilized egg cell.* This germ spot may have a drop of blood near it. Help the children to understand that the baby animal develops within the egg from this small, fertilized egg cell. Older children should learn that this germ spot is composed of the union of two single cells (one from the mother called the unfertilized egg, or *ovum,* and one from the father called the *sperm*). They will want to know that sperm cells from the father bird are introduced by the male into the female *(copulation).* Inside the female bird the sperm cells of the male unite with the ova of the female and produce fertile eggs before the shells are formed on the eggs and before the eggs are laid. From this fertilized egg, a young animal (*embryo*) can develop. Not all eggs are fertile. Most eggs will not develop if they are not fertile. However, such animals as drone bees do develop from unfertilized eggs.

Discuss what causes this germ cell to grow into a baby animal. The children may know that hens' and birds' eggs must be kept warm either by the warmth of the parents' bodies or by an incubator. Help them to understand that providing an environment suitable for hatching eggs is called *incubation* and that, in order to hatch, eggs must be not only *fertile* but also *incubated.* From their reading they may have learned that the eggs of many animals are incubated by the heat from the sun.

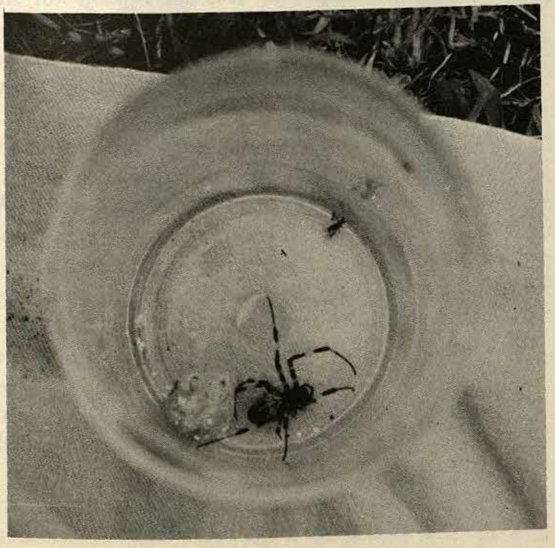
Arrange to visit a place where hens' eggs are being incubated in an incubator. If possible, time this trip so that the children can see some chickens hatching. It also is interesting to young children to have the experience of incubating hens' eggs in a small incubator (it can be homemade) or under a setting hen. This experience can be carried on in a classroom or in some convenient area of the building. When this activity is carried on at school, it should be controlled to prove that only fertile eggs develop young and that heat is necessary for incubation. In addition, older children will want to see the development of the embryo within the egg. This can be accomplished best by selecting, every few days, one fertile egg from those under incubation and opening it. Study pictures and preserved specimens of the development of the chicken embryo.

Help the children to realize that most kinds of fish lay eggs. Have some of the children read about the spawning habits of salmon, trout, bass, goldfish, sunfish, and so on, and report on what they have learned. They should learn that the female fish produces the ova and the male fish the sperm cells, often called *milt,* and that the sperm cells join the ova cells *outside* the female's body at the time she expells them. Use the movie *Sunfish* to show spawning. Many female fish are caught before they spawn and eaten by people who consider the eggs, called *roe,* very fine food. If possible, buy a female shad at the season when you can show the children the hundreds of unlaid eggs inside. Buy some canned roe from the local market so that children can see and taste fish eggs. If there is a fish hatchery near you, make arrangements to take your class there to learn how male and female fish are stripped of ova and sperm cells; how the hatchery causes the sperm cells to join the ova to form fertilized fish eggs; how these eggs are incubated in a tank of water which is warmed by sunshine; and how the baby fish are raised to a size large enough to be used to stock lakes and streams.

In the spring, the children can collect toad and frog eggs for study. They will be interested to watch these eggs develop and hatch into tadpoles, or polliwogs. At the time of spawning, these eggs were fertilized outside the mother's body by the male sperm cells. In pools of water, children frequently see male and female toads in the process of spawning. They find the smaller male toad on the back of the larger female with his forelegs locked around her body. If such a pair of toads are placed in a large tank of water the children can watch the string of eggs being laid by the female and fertilized by the male. Toads' eggs are incubated by the sun's heat.

Female turtles lay eggs. These eggs have been fertilized *inside* the mother turtle by sperm cells from a male turtle. The eggs will be incubated by the heat of the sun warming the soil in which they are buried. Spiders' eggs are fertilized by copulation. Almost any time during the growing season, spiders' egg sacs can be found clinging to the foundations and window casings of buildings or curled up in the leaves of shrubs and trees. Perhaps while your class is hunting for the spider's egg sac, they may also find the spider that laid the eggs and spun the silk case around them. If the spider and its egg case (see Fig. 14.1) are brought into the classroom, they should be placed in a large glass container and arrangements made for adequate food (insects) and moisture. (See Chap. 12, Inquiry 1.) Maybe your children can find several egg sacs made by the same kind of spider. If they can, have them open one of the sacs and see what is inside. They can open the egg sac by pulling it apart with needles. Let the class use a magnifying glass to examine the inside of the case. (They will find that the spider has stored both food and eggs in this case.) Borrow the school microprojector and let the children observe the food and eggs under the low-power objective. Keep the egg sac in a jar of moist sand. When the eggs hatch, observe that the tiny new spiders resemble the parent spiders.

Fig. 14.1 Spider and egg case.



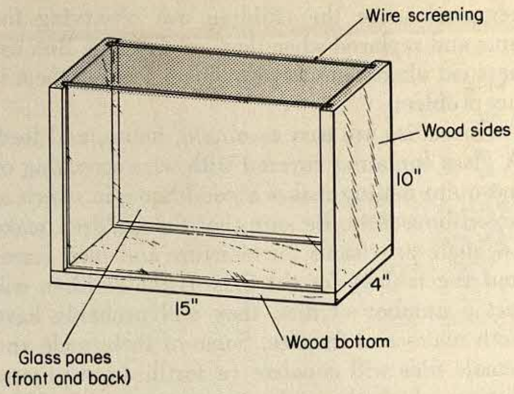


Fig. 14.2 Homemade ant house.

Anthills can be found on the playground, on the edges of sidewalks and roads, and in lawns and fields. Arrange to go on a field trip to collect an anthill. In preparation for this trip, read about the reproduction and life cycle of ants and examine pictures of their eggs, larvae, and pupae. Also at this time, help your class build proper attitudes toward public and private property. Discuss the importance of obtaining permission from the owners. For this field trip, the class will need to take a spade and an ant house partially filled with light-colored sand. An ant house can be built from two panes of glass mounted in a wooden or metal frame (see Fig. 14.2). Fine wire mesh screening can also be nailed to the top frame to allow for ventilation. The cover of the house should be removable so that the ant house can be opened to provide the ants with food and water. Add the ants, their eggs, larvae, pupae, and some of the soil or sand in which the ants are living. When the ant house has been stocked, cover both outside glass panes with black construction paper so that the ants will build their tunnels near the glass. The black paper can be removed when the children are observing the ants and replaced when they are finished. Because ants eat almost any kind of food, feeding them is no problem.

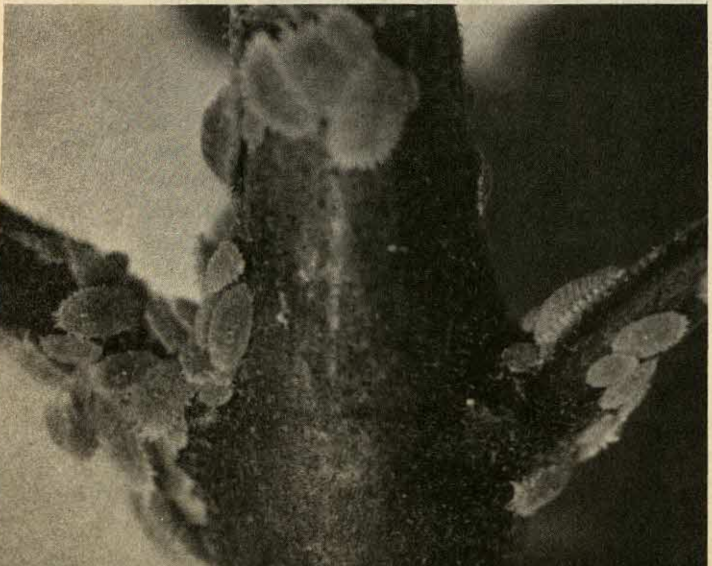
Houseflies are easy to obtain, house, and feed. A glass container covered with wire screening or mosquito netting makes a good home in which to breed houseflies. Be sure that the children make adequate provisions for moisture and food (meat and vegetables) for the flies. If the children collect a number of flies, they will probably have both males and females. Some of these male and female flies will *copulate* (a fertilization process during which the male secretes sperms and the sperms fertilize the eggs inside the female) and the class will be able to observe the entire life cycle of these flies: *egg, larva, pupa,* and *adult.*

Mosquito eggs and larvae (wrigglers) can be found in almost any wet or moist place during warm weather. These larvae should be kept in the same jars of water in which they are collected. Provide adequate ventilation by covering the top of the jar with mosquito netting.

Aphids, or plant lice, flourish on the succulent new leaves and stems of many plants (see Fig. 14.3). Have several members of your class collect pieces of the food plants on which aphids are feeding. Put the food plant in a jar of water and place this jar in a larger glass container. Aphids are so small that magnifying glasses are needed to observe them. If the children look very carefully they may be able to see the *egg,* the *wingless adult,* and the *adult with wings.*

Help your class summarize the experiences they have had. They have learned that female ova must be fertilized by male sperm cells. In some animals fertilization occurs inside the female and sometimes it occurs outside. They have learned that the animals which they studied developed from fertilized eggs and that each young animal when it grew up, resembled its parents. They should have observed that some baby animals when they were newly hatched (spiders, grasshoppers, and praying mantises) resembled their parents and that others (ants, bees, flies, mosquitoes, butterflies, and moths) did not resemble their parents until they had passed through three stages (egg, larva, and pupa).

Fig. 14.3 Aphids.



Many children know that some female animals carry their young *inside* their bodies until the babies are born. Raise white mice or hamsters in the classroom. Help the children apply what they learn from these animals to the birth of kittens, puppies, rabbits, calves, colts, and so on. Older children can learn that the female cell (ovum) of a mammal is *fertilized inside the mother* by the male cell (sperm) and that the fertilized egg that results is incubated *within the mother's body* until the embryo has developed to the stage where it is born. Mammals copulate. Search for information about the length of time different animal embryos need for development before they are born. This is called the *gestation period* of the animal. (See Table 15.7.) For some animals it is days; for others, weeks; and for still others, months.

Find out how one-celled animals reproduce. Use the microscope or the microprojector to examine samples of pond scum and the scrapings from the inside walls of aquaria. Different kinds of one-celled animals should be present in these samples.

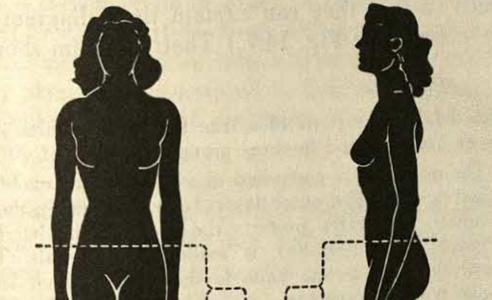
Prepare a culture for raising one-celled animals called *paramecia.* This culture consists of a mixture of straw, hay, or dead leaves and water. A better culture will result if water that is not chlorinated is used. Place the mixture in a warm, dark place for several weeks. During this waiting period, frequently check samples of water from the culture with a microscope. There should be paramecia swimming in the drop of water. These one-celled animals reproduce by dividing into two cells. This method of reproduction is called *fission.*

Perhaps the class can see some paramecia in the process of fission. Paramecia also use another way to reproduce. Two paramecia join together for a short time, exchange material, and separate. This process of exchanging material is called *conjugation.* After conjugation, the two paramecia separate and reproduce by fission.

2. How are human beings reproduced?

In the previous inquiry the students learned that the young of animals develop from fertile eggs. They also learned that mammals copulate and that during copulation the sperm cells of the male mammals are injected inside the female. Fertilization takes place if the sperm cell from the male unites with the ovum of the female.

Fig. 14.4 The female reproductive system. *From Teaching Science in the Elementary School by R. Will Burnett. Copyright 1953 by R. Will Burnett. Reprinted by permission of Holt, Rinehart and Winston, Inc.*



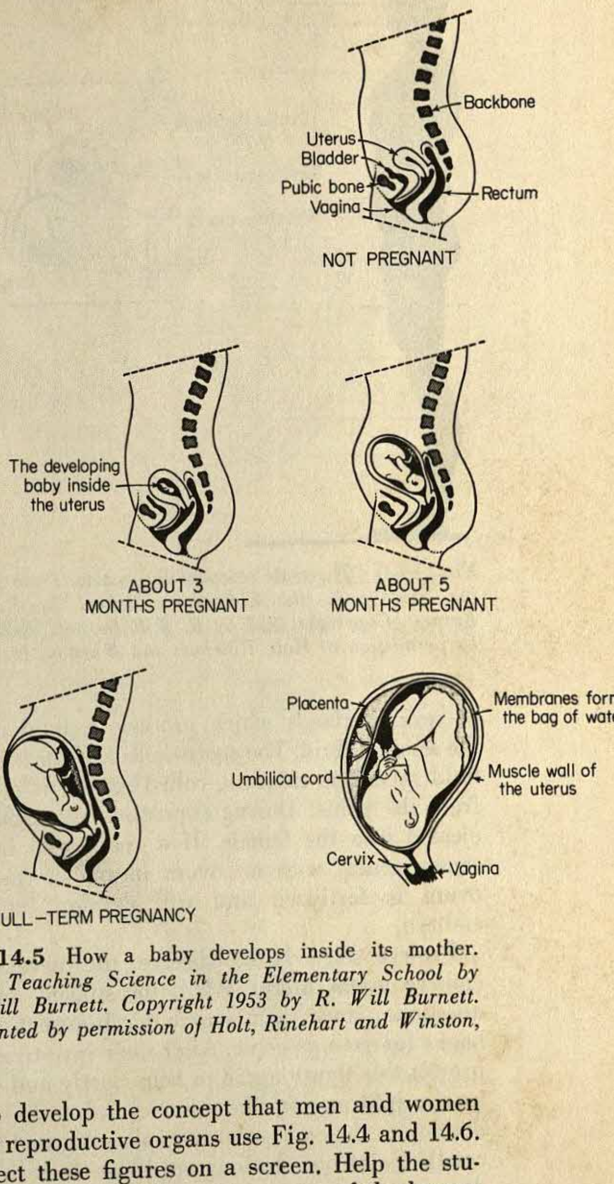


Fig. 14.5 How a baby develops inside its mother. *From Teaching Science in the Elementary School by R. Will Burnett. Copyright 1953 by R. Will Burnett. Reprinted by permission of Holt, Rinehart and Winston, Inc.*

To develop the concept that men and women have reproductive organs use Fig. 14.4 and 14.6. Project these figures on a screen. Help the students identify and learn the names of the human male and female reproductive organs. Encourage the students to look in books for information regarding the function of these organs. A discussion of their investigation should develop these understandings. The ova of the female are in the ovaries. When an ovum has matured, it moves through a Fallopian tube to the uterus. The sperm cells of the male are formed in the testicles. The seminal vesicles and the prostate gland are two

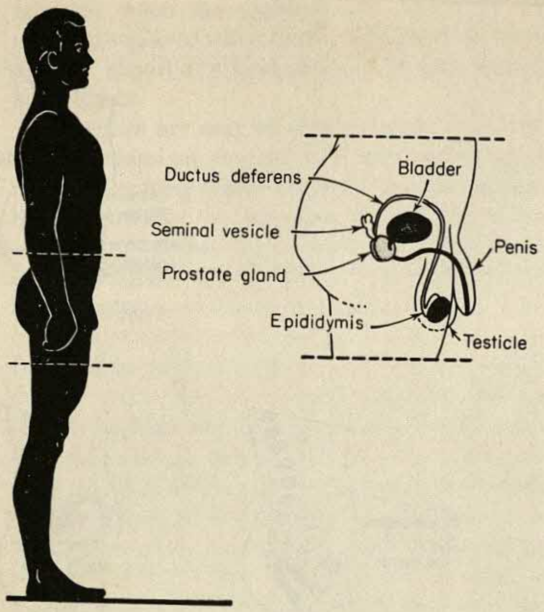


Fig. 14.6 The male reproductive system. *From Teaching Science in the Elementary School by R. Will Burnett. Copyright 1953 by R. Will Burnett. Reprinted by permission of Holt, Rinehart and Winston, Inc.*

of several glands which produce a fluid called the seminal fluid. The sperm cells and the seminal fluid mix. The mixture, called *semen*, is ejected from the penis. During copulation the semen is ejected into the female. If a sperm cell in the semen unites with an ovum in the uterus, the ovum is fertilized and will develop into an embryo.

Project Fig. 14.5. Observe the developing embryo in the uterus. Allow the students to ask questions. Have them search for information in books for young people. After their investigation, project this figure again to help clarify and summarize information like this. Several new organs develop as the embryo grows (placenta, umbilical cord). Point out the long cord-like tissue in the diagram extending from the placenta to the embryo. Explain that the navel is the place where this cord was attached when each human was an embryo.

The embryo receives nourishment from the mother. The mother's blood transports nourishment *to one side of the placenta. On the other side of the placenta,* the embryo's blood absorbs this nourishment and carries it through the umbilical cord to the embryo.

Notice the bag of water that has formed around the embryo. Develop the concept that this sac of water acts as a protection for the baby. At birth the contractions and expansions of the mother's abdominal muscles will cause this baby to move downward, to rupture the sac, and emerge head first.

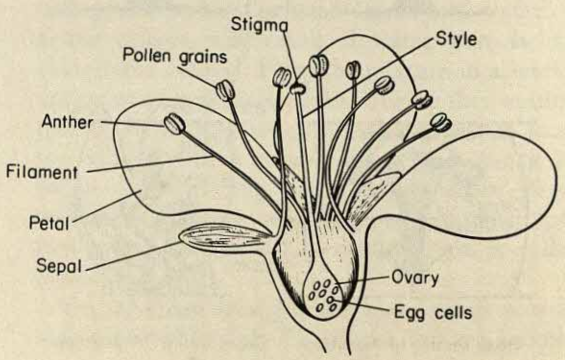
3. How do some kinds of plants reproduce their own kind?

Millions of plants produce seeds from which new plants, like the parent plant, can grow. A seed contains an embryo plant. (Review Chap. 12.) At any time during the growing season, it is worthwhile to visit a garden or field to observe how seeds are produced by flowering plants.

Ask a committee to find a diagram of the parts of a flower in one or more books and to make a large reproduction of it on the chalkboard. Ask them to learn how the parts of the flower produce seeds so that they can explain their diagram to the class. (See Fig. 14.7.) Their diagram should

Fig. 14.7 The parts of a true flower. The parts of a flower are arranged in three groups:

1. The *perianth* is composed of two layers of modified leaves. (a) The outer layer (*calyx*) is made up of sepals. The calyx protects the flower bud. (b) The inner layer (*corolla*) is made up of petals. The corolla attracts the animals that carry pollen from one flower to another.
2. The *stamen* is composed of an *anther* and a *filament*. The stamens are male reproductive organs. The anthers contain pollen grains. The pollen grains contain the male cells (sperm).
3. The *pistil* is composed of a *stigma*, a *style*, and an *ovary*. The pistil is the female reproductive organ. The ovary contains the egg cells and the other cells that produce the food which is stored in the seed.



show: 1) the outer cuplike layer of modified leaves called *sepals* and the inner cuplike layer of modified leaves called *petals;* 2) the *stamens;* 3) the *pistil.* Help this committee explain to the class that the *pistil* is the *female reproductive organ* of the flower because the enlarged egg sac (*ovary*) at the lower end of the pistil contains *unfertilized egg cells.* The *stamens* are the *male reproductive organs* because in their *anthers* are the *pollen grains that contain the male cells* (*sperms*) that are needed to *fertilize the egg cells.* Let them tell of the interesting ways in which the pollen gets from the *anther* to the *stigma* (top of the pistil). Help them explain how, soon after the pollen grain touches the stigma, it begins to grow a long, slender pollen tube, which pushes its way down through the style into the ovary. When the pollen tube has reached the ovary, the male cells (sperm) inside the pollen grain move from the pollen grain, down the tube into the ovary, and fertilize the egg cells. The pollen tube provides the protection the sperm cells need to reach the egg cells in order to fertilize them. In the ovary, the fertilized egg cell divides and multiplies until it grows into a seed containing the tiny plant embryo encased in food storage tissue. (See Fig. 14.8.) If conditions for growth are right, the tiny embryo in each seed will reproduce a new plant. This new plant will be the same kind of plant as the one that produced the seed.

Obtain flowers for the children to examine. Choose such flowers as the blossoms of fruit trees, roses, lilies, tulips, poppies, and phlox. Obtain these plants before the flower buds open, so that the children can watch the anthers develop, open, and become coated with tiny dust-like pollen grains. When the flower has opened, examine the anther and its pollen grains with the microprojector. Try to find the parts shown in the diagram on the chalkboard. As the children take the flowers apart, they should arrange and label each part on paper. Call attention to the long hollow tube of the pistil, which connects the stigma to the ovary. Cut open the ovary of a flower and look for the egg cells or seeds. With a magnifying glass, find the tiny egg cells or unfertilized seeds.

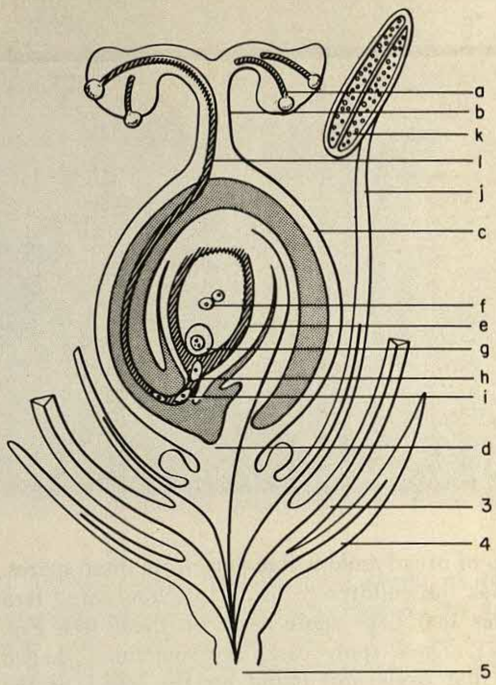


Fig. 14.8 How seeds are produced in flowering plants.

1. Pistil (female reproductive organ): (a) stigma; (b) style; (c) ovary; (d) ovule stalk; (e) embryo sac; (f) cells that form food storage tissue; (g) egg cell; (h) opening to embryo sac.
2. Stamen (male reproductive organ): (i) sperm cells; (j) filament; (k) anther with pollen grains; (l) pollen tube.
3. Petals.
4. Sepals.
5. Flower stalk.

Such plants as molds, mosses, and ferns produce *spores.* Place some moist bread in a dark, warm place. In three or four days, the common black bread mold should have matured on the bread. Examine this mold with magnifying glasses and the microprojector. Appoint several members of the class to look for pictures of this kind of mold in science books. Compare these pictures with what the children see through the magnifying glasses and the microprojector. Prepare a slide of the mold in order to examine it with the lower power of the projector. Use two needles to tear a small piece of the mold off the bread. Spread the mold in a drop of water on the microscope slide. Cover the mold with a cover glass and examine it with the microprojector. Observe the tiny cotton-like threads called *mycelia* and the oval-shaped spore cases. The spores in these cases will be black when they are mature, or ripe.

Brush a needle across some of the mature mold on the piece of bread and wipe the needle on a fresh piece of bread. In several days, another

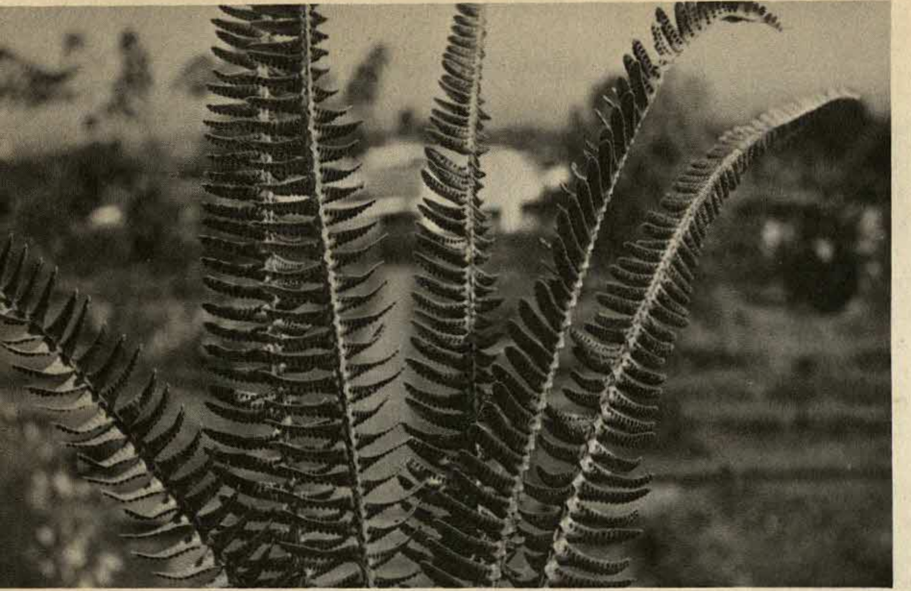


Fig. 14.9 Spore cases on ferns.

crop of bread mold will mature from these spores.

Ask the children to bring to school large fern leaves that have spore cases on them (see Fig. 14.9). These spore cases are sometimes shaped like flat ovals and found on the backs of the leaves. Examine some of these cases with the microprojector. The class might also collect mosses and examine them for spore cases. Reference books on mosses and ferns have pictures that will help the class identify them and their spore cases. If the cases have not matured on the samples, plant the mosses and ferns in glass containers and give the class opportunities to watch spore cases mature.

Children frequently are puzzled about how nonflowering (spore bearing) plants reproduce. Ask some of the more interested and capable children to look up and explain how nonflowering plants reproduce. A large drawing of the life stages of a fern will help them to explain it. The mature fern plant produces the spores. A spore develops into the tiny heart-shaped plant (prothallium) which produces the egg and sperm cells. (See Fig. 14.10.) Observe the root hairs

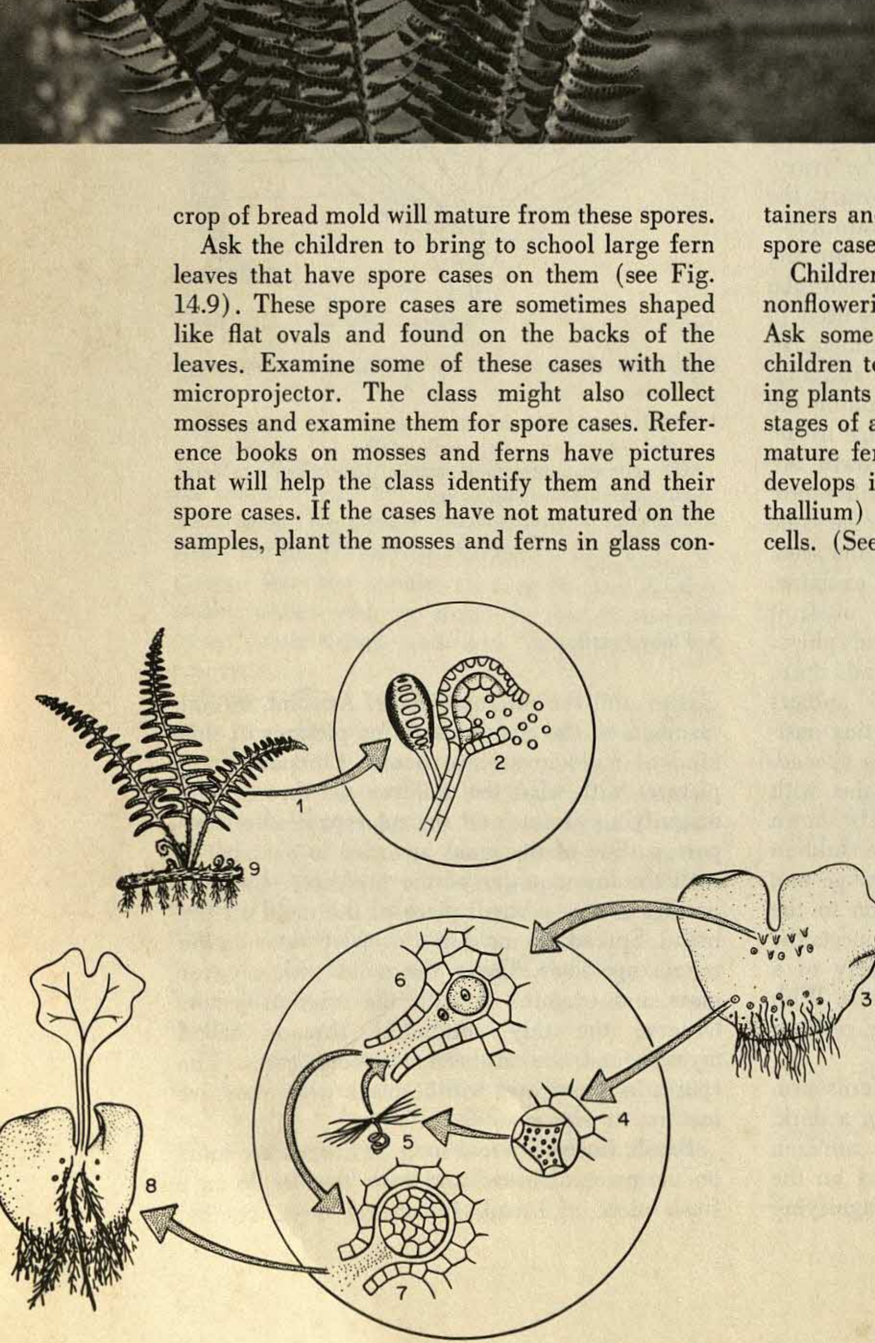


Fig. 14.10 Life cycle of a fern.

1. Spore cases on underside of fern leaf.
2. Spore cases magnified to show release of spores.
3. Spore germinates into prothallium containing male and female reproductive organs.
4. Male reproductive organs magnified to show sperm cells.
5. Sperm magnified to show cilia which enable it to swim into the female reproductive organ.
6. Female reproductive organ magnified to show unfertilized egg cells.
7. Fertilized egg or embryo magnified.
8. Fertilized egg germinates into young fern plant.
9. Mature fern showing spore cases under its leaves.

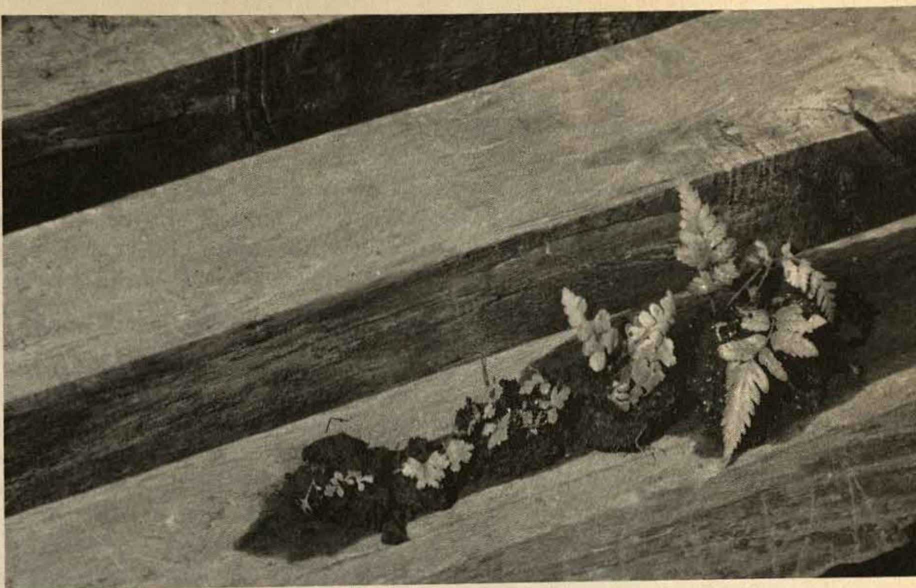


Fig. 14.11 Young fern plants in early stages of growth.

and two kinds of "pockets" on the under surface of the prothallium. The round pockets are the *male reproductive cells and contain the sperms.* The long pockets are the *female cells and contain the unfertilized eggs.* The sperm cells "*swim*" through the film of water on the under surface of the prothallium to the egg cells. The function of the prothallium is the same as the function of the flower of a seed bearing plant. The fertilized egg grows into the fern plant that produces the spores. Try to find some of these tiny heart-shaped plants (prothallia) in damp woods, on damp decaying logs, or along the banks of streams. Warn the class that they will be very difficult to find because they are so small. (See Fig. 14.11.)

Some one-celled plants reproduce by simple cell division (fission). Blue-green algae reproduce by this method. Ask the class to look for these blue-green algae. Look for these algae on the trunks of trees. Obtain permission to remove a few pieces of bark upon which the algae are growing. Firewood, with bark on it, also can be used. Borrow the school microprojector and let the children examine the algae. Place some of the powder-sized particles in a beaker containing a small amount of water. Mix the algae in the water with a stirring rod. Remove a small sample of this mixture with a medicine dropper and place one drop of it on the center of a clean microscope slide. Lower a cover glass in a horizontal position over the drop of water containing the algae. The cover glass will flatten the water droplet, which will make it easier to focus the objective of the microprojector. Describe the shape of the algae seen through the microprojector. (They are single round cells grouped in clusters, or colonies.) Compare the colonies seen on the slide with printed pictures of blue-green algae (pleurococci). Put the remainder of the blue-green algae on the small pieces of bark and place the bark in the terrarium or in a glass jar partially filled with moist soil. Set the container in a sunny window. The blue-green algae will multiply very rapidly.

Borrow from the high school biology teacher a prepared slide that shows how single cells, like those of blue-green algae, multiply. Pictures of cell division called *fission* can also be found. (When single cells reproduce by fission, the cell constricts itself in one area until it divides into two cells.)

Pond scum composed of many different kinds of green algae clings to wet rocks, pieces of twigs, and other parts of plants found in shallow water. The school aquarium also is an excellent place to collect these kinds of plants. Put some of these green algae on microscope slides and examine them with the microprojector. Also place some of these algae in a glass container of pond water and put the container in a sunny window. In a few weeks, these algae will produce hundreds of new cells by simple cell division or fission. Some kinds of algae also reproduce by a process called *conjugation.* (When single cells reproduce by the process of *conjugation,* two single cells join together, exchange some life-giving material, separate, and continue to reproduce by fission for some generations, until they again conjugate.) Perhaps the children will be able to see both *fission* and *conjugation* on their slides. Have several members of the class look for pictures in biology books that illustrate these two kinds of reproduction. Use the pictures to help the children look for similar examples on their slides.

In Chapter 2 (page 21), a problem was discussed that might be utilized at this time to help your children develop an awareness that bacteria reproduce by simple cell division like the algae. Use sterile petri dish cultures from the science supply room or ask the science consultant or a science teacher to help with this problem. Keep one sterile culture for a control. Remove the cover from one dish and have a child rub his finger across the agar. Cover the dish immediately. Have another child open a second dish and hold it in front of his mouth and cough. Close this dish quickly. Open a third culture dish and expose it to the air for a few minutes. Cover this dish. Keep the three experimental dishes and the control in a warm place for several days. Clusters of a thin scumlike growth will develop on the agar in the three experimental dishes. No growth should appear in the control dish. The tiny bacteria plants that make up these clusters on the agar are so small that the children cannot see the individual plants unless they can view them through an oil immersion microscope. However, pictures of the shapes of different kinds of bacteria can be found in textbooks.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Animals reproduce their own kind. Some animals, at birth, resemble their parents; others do not resemble their parents until they have grown up. Most kinds of animals develop from fertile eggs. A fertile egg is formed by the union of a female cell (ovum) with a male cell (sperm). Some eggs are fertilized inside the mother's (female's) body; some are fertilized outside the female's body. The embryo in a fertile egg needs heat in order to grow. Some animals use their body heat to incubate their eggs. Other eggs are incubated by the heat from the sun. The embryos of mammals develop inside the female. One-celled animals reproduce by fission and conjugation.

2. Our body contains a reproductive system. The testicles in the male reproductive system produce sperm cells. The ovaries in the female reproductive system contain the egg cells. The semen from the male is injected into the female during copulation. If an ovum is fertilized by a sperm in this semen, an embryo develops. After fertilization several new organs develop that nourish and protect the embryo as it grows.

3. Plants reproduce by seeds, spores, and cell division. Flowering plants produce seeds. A seed contains an embryo plant formed from the union of a female egg cell and a male sperm cell. Many kinds of nonflowering plants produce spores. A spore grows into a tiny plant which produces both male and female cells. A mature plant develops from the union of these cells. Both seed-bearing and spore-bearing plants develop from fertilized egg cells. One-celled plants reproduce by cell division and conjugation.

Chapter Fifteen

How Man Classifies Things

A classification of living things is like a filing system. It is a man-made way of filing known information about closely related groups of things so that the information is easy to find and use. The classifications used by scientists were made long ago and, in general, serve as excellent filing systems. Some information, however, cannot be filed into these original classifications. For example, some viruses are classified as nonliving and yet, under favorable conditions, they take in soluble food and reproduce. The duck-billed platypus has a bill and lays eggs as birds do, but nurses its young as do mammals.

Living things are classified into two large groups, the plant and animal kingdoms. Most plants have cell walls composed of a starch-like compound called *cellulose*. Plants either make their own food or take in soluble food from their environment. Adult plants usually are stationary and respond much more slowly than animals do to such environmental factors as light, heat, and foreign objects with which they come in contact. Many plants have specialized tissues for the manufacture and storage of food. On the other hand, most animal cells are surrounded by a membrane composed of protein. Animals can usually ingest solid food. Higher animals have developed specialized external structures and internal organs.

Actually there is no clearly marked distinction between some forms of lower plants and animals. The euglena (see Fig. 15.1) is classified by some biologists as a plant and by others as an animal. Still other biologists classify it in a third king-

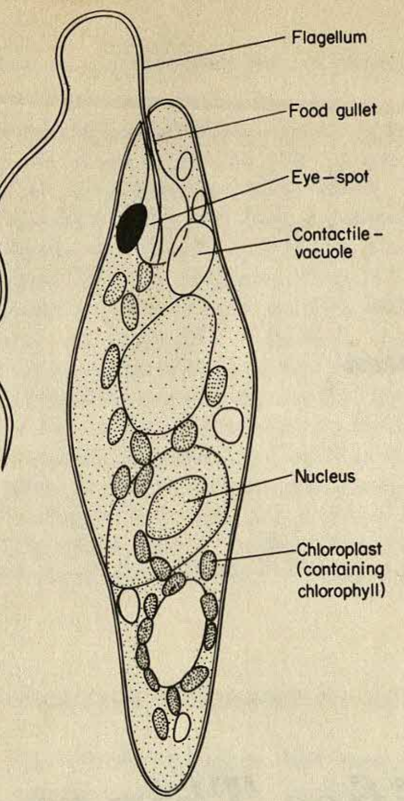


Fig. 15.1 Plant-like animal, euglena.

dom called *Protista,* meaning that it has characteristics of both plants and animals. If Aristotle had had a microscope and known of the existence of such tiny plantlike animals, there might have been three kingdoms of living things instead of the two that are used today. These three kingdoms would have consisted of plants, plantlike animals, and animals. Then some of the lower forms of plants and animals now known could be easily classified as plantlike animals.

INQUIRIES

1. How are living and nonliving things classified?
2. How are plants classified?
3. How are animals classified?

1. How are living and nonliving things classified?

One way for children to solve this problem is to have them help you make a collection of the many things that are in a classroom. Then ask them to arrange related materials in groups. This can be done in an open discussion period in which every child is free to make suggestions. After arranging and rearranging the articles, the class should be able to arrive at a classification that divides materials into:

1. Things that are alive;
2. Things that once were alive;
3. Things that never have been alive.

Tell them to place the things they do not know how to classify in a fourth group called "Things We Do Not Know How to Classify." These unclassified objects can serve as challenging problems for the children to solve. Some of the common objects of the classroom are inventoried in Table 15.1. Encourage the children to bring other things from home for the class to classify.

Develop the idea that things that are alive and things that once were alive are compounds of the elements carbon (C), hydrogen (H), oxygen (O), and nitrogen (N). Help the children to understand that scientists classify all substances that contain the element carbon as *organic* compounds and ones that lack the element carbon as *inorganic* compounds. Table 15.2 lists some of the organic and inorganic compounds the children may know. If the list of organic and inorganic compounds the class makes contains the names of other compounds, have the children look up the names of the elements in these compounds. Question them about the source of the carbon in some of the compounds. From their past experiences, they may know that carbon dioxide is a waste product of oxidation in both plants and animals. They also may know that green plants manufacture carbohydrates, fats, and proteins; that the bodies of animals are mainly composed of proteins, fats, and water. Find out whether your class knows the source of the calcium carbonate present in some rocks. This compound is formed by several kinds of algae, sponges, corals, crustaceans, and mollusks. (See Table 15.2.) The earth's atmosphere, hydrosphere (oceans), and lithosphere (rock sphere) are the chief sources of inorganic compounds.

2. How are plants classified?

The plant kingdom is divided into four major groups called *phyla.* The names of these four

Table 15.1

A SAMPLE INVENTORY CLASSIFYING SOME OF THE THINGS IN THE CLASSROOM

Things That Are Alive	Things That Were Once Alive	Things That Never Have Been Alive
Classmates	All things made of	All things made of
	Wood	Metal
Teacher	Natural or synthetic rubber	Glass
House plants	Natural or synthetic fibers	Most stones
	Plastic	
Both large and microscopic plants and animals present in the aquarium, terrarium, and vivarium	Bone	Water
	Skin	
	Shell	Salt
	Chalk	
Bacteria and mold spores	Graphite in "lead" pencils	
In the air		
In the soil in potted plants, terrarium, and vivarium	Crayons	
On everyone's skin	Glue	
In everyone's mouth and nose	Fibers in paint brushes	
	Bristles of brooms	
	Some stones	
	Foods	

Table 15.2

ORGANIC AND INORGANIC COMPOUNDS

Organic Compounds	Kinds of Atoms in Their Molecules	Inorganic Compounds	Kinds of Atoms in Their Molecules
Carbon dioxide	Carbon, hydrogen, oxygen	Quartz	Silicon, oxygen
Sugar	Carbon, hydrogen, oxygen	Mica (white)	Aluminum, hydrogen, potassium, silicon, oxygen
Starch	Carbon, hydrogen, oxygen	Feldspar (orthoclase)	Aluminum, oxygen, potassium, silicon
Cellulose	Carbon, hydrogen, oxygen	Iron oxide	Iron, oxygen
Fat	Carbon, oxygen, hydrogen, nitrogen	Calcium oxide	Calcium, oxygen
Protein	Carbon, oxygen, hydrogen, nitrogen	Peroxide	Hydrogen, oxygen
Calcium carbonate	Calcium, carbon, oxygen	Hydrochloric acid	Hydrogen, chlorine
		Table salt	Sodium, chlorine
		Water	Hydrogen, oxygen

phyla are the *Thallophytes, Bryophytes, Pteridophytes,* and *Spermatophytes* (Table 15.3).

The simplest plants belong to the first phylum called *Thallophytes. Bacteria, algae,* and *fungi* belong to this phylum. Review the experiences suggested for bacteria, nongreen plants (fungi), and algae in Inquiry 3, Chap. 14. These very simple plants look quite different from the plants

Table 15.3

A BRIEF SURVEY OF SOME OF THE MORE IMPORTANT PHYLA IN THE PLANT KINGDOM

Phylum	Habitat	One-celled	Many-celled	Reproduction	Specialization
1. Thallophytes					
Bacteria	Moist or water	Yes	No	Asexual cell division	None; life processes carried on by single cell
Fungi (molds, mushrooms, toadstools) 80,000 species	Moist or water	Some	Largely	Most fungi produce wind-scattered spores; largely asexual; some sexual as well as alternation of generations	Beginning as single cell carries on reproduction for a group of cells Group of cells transport food Groups of subterranean cells secrete enzymes which change food into a soluble form
Algae	Largely aquatic	Usually	Some	Largely asexual; some reproduce by alternation of generations; many kinds of simple algae produce spores which swim	Beginning of organelles (little organs in the individual cells, such as nucleus, varioles, and plastids that carry on life functions)
2. Bryophytes (mosses) 16,000 species	Moist land	None	All	Alternation of generation; produce spores in capsules	Organs for reproduction, food making, storage, food and water transportation, and supporting structure (beginning of roots, stems, and leaves)
3. Pteridophytes (ferns) 4500 species	Moist land	None	All	Produce spores; fruit in dots; alternation of generations	Specialized organs for various life processes; have true roots, stems, and leaves but do not produce seeds
4. Spermatophytes (seed-producing plants) 133,000 species	Varieties have adaptations enabling them to live in a wide variety of habitats: aquatic, moist, arid and semiarid, cold, warm, and hot	None	All	Sexual	Specialized organs for various life processes; have true roots, stems, leaves, and produce seeds; have supporting structure of either cellulose or lignin

in the other three phyla. They lack the various parts that we think of when we visualize a green plant. The Thallophytes have no roots, stems, leaves, or flowers. Many of them are very small. Many kinds cannot be seen without a microscope, and many of them are one-celled organisms. Encourage the class to study some of the pictures of the Thallophytes in reference books. Call their attention to the great variety of shapes and sizes of the different kinds of plants that belong to this group. Have the children talk about the kinds of places in which these plants live (water, tree trunks, soil, swamps, animals).

Mosses belong to the second phylum called *Bryophytes*. Ask the children to describe some of the places in which they have seen these plants growing (woods, banks along bodies of water, swamps). Review the experiences suggested for mosses in Chap. 14, Inquiry 3. Have the children examine the stems and *rootlike* appendages of mosses with a magnifying glass. Find out whether the children know the functions of the roots and stems of plants. (The roots and stem transport water and other soluble materials to all parts of the plant. Roots also help to anchor the plant in the soil. Stems of plants that grow upright usually have supporting tissue composed of either cellulose or lignin.) After the class has discovered the functions of roots and stems, have them decide why mosses are commonly found growing in moist soil and algae in water.

Ferns belong to the third phylum called *Pteridophytes*. Review the experiences suggested for ferns in Inquiry 3, Chap. 14. Remove a fern from the terrarium and let the class compare this plant with a moss plant. Have the children observe at least two differences between mosses and ferns. (Ferns grow much taller and have leaves. The fern plant has roots and its stems are much more rigid.)

Flowering plants belong to the fourth phylum called *Spermatophytes*. Review the experiences suggested for flowering plants in Inquiry 3, Chap. 14. These plants have well developed roots, stems, and leaves; they reproduce by means of seeds. A number of factors contribute to the success of the flowering plants, among them, strong supporting tissues, highly developed conducting tissue, and a method of reproduction that can be carried on in many different kinds of habitats. The male cell (sperm) of flowering plants can reach the female cell (egg) without swimming through water or a film of water as male cells of ferns and mosses must do in order to reach the female cell. (See Fig. 14.8.)

Discuss some of the important differences between the four major phyla of plants. Have the class summarize their knowledge.

Take the class on a field trip to collect at least one kind of plant from each plant phylum.

3. How are animals classified?

Study Table 15.4. Observe that groups of plants with similar characteristics are also classified by phyla (see Table 15.3). Show the children how the large groups, plant and animal —phyla—are subdivided into subphyla, class, subclass, order, family, genus, species, and race (see Table 15.5). Encourage some of the more interested students to use advanced textbooks and references to classify in this manner a few animals in the various phyla. Some of them may wish to classify themselves.

In the latter part of the chapter, there is a compilation of interesting information about some animals, together with experiences that will help the children learn about some of the differences and likenesses of these animals.

Observe living animals that belong to the different phyla and classes. Collections containing shells, starfish, sand dollars, corals, and the external skeletons of crabs and lobsters can be used to illustrate the variety of size, shape, and the external structure of some of the invertebrates. Collect and arrange pictures on the bulletin board of some of the animals in each of the different phyla. Give the students many opportunities to use science textbooks and reference books to help answer the questions asked. Use movies, colored slides, and filmstrips to supplement and reinforce what they are learning.

Some interesting information about animals that live in most areas and some experiences that children can have in learning about them

Clams *Distinguishing physical features:* Two parts to the shell. The parts are fastened together with "hingelike" tissues called *ligaments.*

How they are reproduced: There are male and female clams. The eggs are fertilized outside the body. The eggs cling to the gills of

Table 15.4

A BRIEF SURVEY OF SOME OF THE MORE IMPORTANT PHYLA AND CLASSES IN THE ANIMAL KINGDOM

Phylum	Class	Number of Species	Habitat	How They Reproduce	Outer Covering
1. Protozoa		15–20,000	Water, moist soil, and the bodies of animals	Cell division and beginnings of sexual reproduction	Some are naked, others have a firm layer of protoplasm, and some a thin coating of lime or silicon
2. Sponges		15,000	Most kinds in the sea, a few in fresh water	Budding and sexual reproduction	Lime, silicon, or fibrin
3. Corals, jellyfishes, and sea anemones		9,000	Most kinds in the sea, a few in fresh water	Cell division, budding, and sexual reproduction	Corals: lime; others, a thin membrane
4. Comb jellies, sea walnuts, sea jellies		100	The sea	Sexual reproduction	Thin membrane
5. Flatworms		7,000	Parasites; in fresh and salt water	Cell division, sexual reproduction	Smooth, soft bodies
6. Round worms or thread worms		3,500	Moist places, fresh and salt water, and the bodies of most large animals	Sexual reproduction	Moist, soft, naked bodies
7. Starfish, sand dollars, sea urchins, sea cucumbers, sea lilies		5,000	The sea	Sexual reproduction	Shell-like
8. Jointed worms (earthworms and leeches)		5,000	Moist places, fresh and salt water	Sexual reproduction	Soft, naked bodies
9. Wheel animalcules (rotifers)		1,500	Fresh and salt water, the bodies of animals	Sexual reproduction	Shell-like skin
10. Mollusks (snails, clams, oysters, slugs, and cuttlefish)		80,000	Fresh and salt water, land	Sexual reproduction	Usually a hard shell

11. Arthropods (jointed-leg invertebrates)	Crustaceans (lobsters, crayfish, crabs, and sow bugs)	20,000	Most in fresh and salt water; some in moist places on land; others in the bodies of animals	Sexual reproduction	Limelike substance called *chitin*
	Centipedes, millipedes	2,000	Crevices of rocks, under bark, and on land	Sexual reproduction	Thin layer of chitin
	Arachnids (spiders, mites, scorpions, ticks, and king crabs)	27,500	Most live as parasites on animals; few in water	Sexual reproduction	Chitin
	Insects	700,000	Everywhere	Sexual reproduction	Chitin
12. Chordates (subphylum: vertebrates)		41,000	Everywhere	Sexual reproduction; some lay eggs, other give birth to their young	Varied
	Fishes, sea squirts, lancelets, lamprey eels, hagfishes, sharks, true fishes, and lung fishes	15,000	Fresh and salt water	Lay eggs	True fishes have scales
	Amphibia (salamanders, congo snakes, newts, mud eels, toads, and frogs)	2,000	Water; moist places; some never enter water	Sexual reproduction, lay eggs	Moist skin; dry, wartlike skin
	Reptiles (alligators, crocodiles, lizards, snakes, and turtles)	4,000	Most in low, moist, hot forests; some in hot dry places; some in deserts; others in forests and moist places in the temperate zones	Sexual reproduction, most lay eggs, some retain egg in body until it hatches	Hornlike scales
	Birds	15,000	Ground, trees	Sexual reproduction, lay eggs; most species, female incubates eggs	Feathers
	Mammals	4,000	Ground, trees, water	Sexual reproduction, most give birth; all nurse young	Usually hair or fur

Table 15.5

HOW ANIMALS AND PLANTS ARE CLASSIFIED

Kingdom	Animal	Plant
Phylum	Chordata	Spermatophytes (seed plants)
Subphylum	Vertebrate	
Class	Mammals	Flowering plants
Subclass	Placental mammals	With two cotyledons or seed leaves
Order	Flesh-eating	
Family	Doglike	Maples
Genus	Dog	Maples and related trees
Species	Domestic	Maple
Subspecies	Sheep dog	Sugar
Race	Scotch collie	Local variety

the female until they hatch. Their eggs are commonly found on the gills of clams from late summer until spring.

Kind of parental care: Young fend for themselves after they hatch from the egg.

Seasonal activities: They are dormant during cold weather. The animals burrow in the muddy bottoms of bodies of water or under dead plant and animal debris.

Suggested experiences: Clams may be found in the mud in shallow waters. Observe the delicate lines on the shell. By counting the number of these lines, the approximate age of the animal can be determined. Note how small the animal was when it first hatched from the egg. The small oval-shaped line near the hinges of the shell will give the children some idea of the size of the clam when it hatched from the egg.

Snails *Distinguishing physical features:* The body of the snail consists of a head, neck, foot, and hump. The hump is enclosed in a spiral-shaped shell. The hump contains the viscera (such organs as the stomach, heart, etc.). The head and foot of the snail can be withdrawn into the shell.

How they are reproduced: In some species, the same animal has both male and female reproductive organs. But the union of two animals is necessary for the fertilization of the eggs. The eggs are fertilized internally.

Kind of parental care: Snails fend for themselves after they hatch from the eggs.

Seasonal activities: Similar to those of clams.

Suggested experiences: Land snails can be found in moist places. Look for water snails in the same places in which clams are found. Observe the snails as they move and feed. Look for a pair of short tentacles on the head; these are organs of smell. The longer pair of tentacles have eyes. Look for two small openings near the thickened part of the mantle—the mantle attaches the foot to the hump. The opening nearer the front of the body is the respiratory pore. The opening behind this pore is the anus from which wastes are excreted.

Insects *Distinguishing physical features:* The body has three easily recognized parts: head, thorax, and abdomen. Three pairs of legs are attached to the thorax. The bodies of insects are covered with a hard covering called *chitin.*

How they are reproduced: The eggs are fertilized internally and hatch outside of the body.

Kind of parental care: Except for a few kinds of insects, such as bees and ants, no care is given to the young after the eggs are laid. Before they mature, some kinds of insects (moths, butterflies, bees, wasps, dragon flies, caddis flies, and others) pass through four stages: egg, larva, pupa, and adult. The young of these insects do not resemble the adult until they emerge from the pupal stage. Insects that pass through these four stages are said to undergo complete metamorphosis (change in body form). Insects that resemble their parents when they hatch from the egg (grasshoppers, crickets, praying mantises, walking sticks and others) are said to undergo incomplete metamorphosis. In incomplete metamorphosis, the animal passes through only three stages: egg, nymph, and adult.

The wings of flying forms of insects that undergo incomplete metamorphosis are encased in chitinous wing cases until they attain full growth. If an insect can fly, it is an adult.

The young of insects that pass through either complete or incomplete metamorphosis increase in size by molting (shedding their skin). See Fig. 15.2.

Seasonal activities: The adults of many kinds of insects that live above the ground die in late autumn. The young of these kinds of insects survive the winter months in either the egg, larval, nymph, or pupal stages.

Suggested experiences: Collect insects in the various stages of their life cycles and observe them develop. Give the class the opportunity to observe one or more kinds of insects that pass through complete and incomplete metamorphosis. Use reference books to identify some kinds of insects that are found in the area. Read about some of the beneficial and harmful kinds of insects. List some questions the class would like to have answered about beneficial and harmful insects and invite the representative of the farm bureau or the conservation department to discuss these questions with the children.

Amphibia *Distinguishing physical features:* Most amphibia are covered with moist, porous skins. Legless, or wormlike, amphibia are found in subtropical and tropical regions. Such amphibia as mud puppies and salamanders have four legs and a tail. Adult frogs and toads have four legs and are tailless. The toad's skin is rough and warty.

How they are reproduced: The eggs are usually fertilized after they are laid in water.

Kind of parental care: Most young fend for themselves after they hatch from the egg.

Seasonal activities: Amphibia living in the temperate zone lay their eggs in the early spring. These kinds of amphibia are dormant during the winter months. During summer days when the temperature is very high, amphibia and such animals as clams and snails estivate. During dormancy periods, the amphibians burrow into the soil or the muddy bottoms of bodies of water.

Suggested experiences: Find out whether the children believe that they will get warts if they handle toads; that all toads are poisonous; that during heavy rainstorms in the spring of the year, it rains frogs and toads. None of these superstitions is true. Have them check what authorities say about these superstitions and report their findings to the class.

Have the children collect frog eggs and toad eggs and watch them develop into tadpoles. Let them examine the eggs with a magnifying glass and observe the development of the embryo.

Reptiles *Distinguishing physical features:* The bodies of most reptiles are covered with scales or bony plates. The skin of some kinds of reptiles, such as the chameleons, are covered with granules.

How they are reproduced: The eggs of reptiles are fertilized internally. Turtles and lizards deposit their eggs in the ground. The females of most species of snakes retain the eggs in their bodies until they hatch.

Kind of parental care: After the young hatch from the egg, they fend for themselves.

Seasonal activities: In the temperate zone, animals breed in the spring. Animals living in this zone become dormant during the winter months. They burrow into the soil, under rocks and logs. Reptiles and the amphibia that have warty skins molt one or more times during the season. The toad's molt is never found because this animal swallows its skin as soon as it is shed.

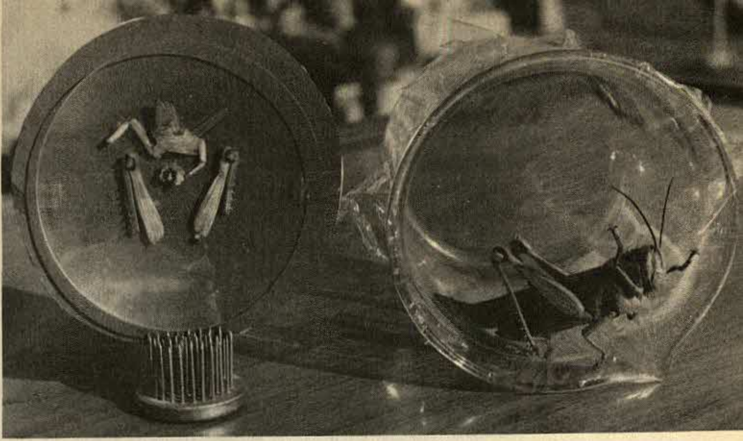


Fig. 15.2 Grasshopper and its molt.

Suggested experiences: Find out whether there are any poisonous reptiles in the community. Most kinds of reptiles that live in the temperate zones are harmless and beneficial.

Do the children believe in any of these superstitions? Snakes are slimy. (A snake's skin is dry and scaly. The skins of many amphibia are slimy.) Black snakes swallow their young when they are in danger and spew them out after the danger has passed. (This is not true. The young slither under things and hide.) Milk snakes steal milk from cows. (This is untrue. Milk snakes are frequently found in barnyards because they feed on mice and rats.) Discuss some of these superstitions with the children. Have your class read about the food habits, protective adaptations, and activities of snakes.

Fish *Distinguishing physical features:* They are variable-temperature, completely aquatic vertebrates. They have gills and commonly have fins and a body covering of scales; their bodies are usually elongated.

How they are reproduced: In the north temperate zone, the spawning period of most fish is in June and July. When the temperature of the water is between 70–80°F, the eggs are laid on submerged rocks and branches. The eggs are usually fertilized externally.

Kind of parental care: Most fish do not care for their young after the eggs are laid.

Seasonal activities: The mud minnow is believed to burrow in the mud at the bottom of the body of water. Other fish that live in small bodies of water are believed to move to deeper water during the winter months.

Suggested experiences: Observe the gills of the fish in the aquarium. Find out how fish remove oxygen from the water. (The gills contain many small blood vessels. The red corpuscles in the blood combine with the oxygen as it seeps through the lining of the blood vessels.)

Why do fish seem to be gulping water? How does the fish get rid of the water it gulps? (The water enters the mouth, flows over the surfaces of the gills and out through the gill slits.) When does the fish gulp water more frequently; when it is quiet, or when it is swimming? (When it is swimming.)

Observe the body motions and movement of the fins when a fish is swimming.

Birds *Distinguishing physical features:* Birds have outer coverings of feathers and down. The fore limbs of birds have become modified into wings, vestiges of wings, or flippers.

How they are reproduced: Bird eggs are fertilized before they are laid. The majority of birds mate and live together for only one season.

Kind of parental care: Most species of birds build nests and incubate their eggs. The eggs of birds vary greatly in size, color, and number. The period of incubation for the eggs of different species of birds varies from 12 to 42 days.

Table 15.6

INCUBATION PERIODS FOR SOME BIRDS

Name	Number of Days
Canary	14
Chicken	21–23
Duck	26–28
Goldfinch	12–14
Goose	29–31
Pigeon	16–17
Robin	14
Swan	42

Some species of birds can walk as soon as they hatch from the egg. Other species of birds are helpless for several weeks after they hatch. Most species of birds care for their young until the down that covers the body of the young has been replaced by feathers.

Seasonal activities: Birds usually molt their feathers in the fall. Some species of birds molt part of their feathers in the spring, before the mating season.

Many kinds of birds that nest in the temperate zone migrate in the late summer and return to their breeding place in the early spring. Many theories attempt to explain why birds migrate. The periodic migrations of birds are probably influenced by a number of factors, such as decrease in the number of hours of daylight, reproductive instincts, and the instinct to follow the leader. Migratory flights are usually made on clear nights. Bird songs are most frequently heard during the mating seasons. Some species of birds raise several families of young during the spring and early summer months.

Suggested experiences: Learn to identify some of the common birds in the school area. Read about the food and nesting habits of birds. Read, too, about the adaptations of their beaks that enable them to eat different kinds of food and about the adaptations of their feet that enable them to run up and down tree trunks, to cling to tree trunks while they feed, to perch on branches, wade in shallow water, and to swim.

Borrow an incubator in which children can incubate and care for eggs.

Excellent colored slides and movies are available to give the children further experiences about the life activities of birds and also to help them to learn to identify them.

Discuss the incubation periods for some of the common birds shown in Table 15.6. Look through encyclopedias and books on natural history and try to find the incubation periods of some of the other kinds of birds in the community.

Mammals *Distinguishing physical features:* The bodies of most mammals are covered with hair or fur. Scales are present on the bodies of a few mammals and on the tails of such animals as beavers, muskrats, rats, and mice. Mammals usually have four appendages or vestiges of these appendages. These appendages are adapted for different kinds of locomotion, such as walking, running, hopping, jumping, and swimming. The forelimbs of some mammals are adapted for grasping food and manipulating objects. Bats fly by means of a leathery membrane that is attached from the forelimbs to the hind legs.

How they are reproduced: The eggs of mammals are fertilized inside of the body of the female. Most mammals give birth to their young.

Kind of parental care: The female mammal suckles its young and cares for them until they are old enough to search for their own food. Some mammals mature in one season; others take longer periods of time. Many kinds of mammals train their young to hunt and fish. Parental care of mammals often continues until the young mammal is old enough to mate.

Seasonal activities: Most mammals that live in the temperate zone remain active during the winter months. When the weather is very cold, many mammals seek shelter in burrows in the ground, in caves, and in hollow tree trunks and logs. The fur of mammals grows thicker in the fall of the year. This thick coat helps to retain the animal's body heat. Mammals, because they have constant temperature, can adjust more readily to cold weather than animals such as amphibians and reptiles that have variable temperature. The body temperature of most mammals varies very little from one day to the next and from one season to another. Their body temperature is said to be *constant.*

Some mammals do hibernate. The woodchuck is the deepest sleeper of them all. Woodchucks usually go into their burrows in early October and do not come out until early in April. Raccoons, gray squirrels, and skunks hibernate during December and January. Chipmunks sleep very lightly during the winter and frequently wake up to feed. The red squirrel is usually active throughout the winter season.

A few mammals, such as bats, bison, fur seals, reindeer, and lemmings, migrate.

Find out whether the children believe in any of these superstitions: If fur-bearing animals grow unusually heavy coats of fur in the autumn, the winter will be very long and cold. If a ground hog sees its shadow on February 2, the spring will be late. Some mammals, knowing that winter is coming, prepare for it by storing food. (Squirrels hide nuts and seeds in many different places but may not return to eat them. Beavers do store food and feed on it during the winter months, but they do it instinctively.) Help the children develop the concept that man is the only living thing that is capable of planning for his future.

Make an inventory of some of the mammals in the community.

Give the children opportunities to observe and care for mammals, such as white rats, white mice, guinea pigs, and rabbits. Plan to have these animals brought to school during the mating season. Let them watch the male and female mate. If it is at all possible, have the children observe the birth of one or more kinds of mammals.

Children are very interested in the gestation period of animals that are born alive. Have some child copy Table 15.7. Encourage the more interested children to find the gestation periods of other kinds of animals and add them to the list.

Table 15.7

GESTATION PERIOD OF DIFFERENT ANIMALS

Name	Length of Time	Name	Length of Time
Black snake	60 days	Kangaroo	35 days
Cattle	9 months	Oppossum	20–26 days
Dog	62 days	Man	270–290 days
Elephant	2 years	Pig	16 weeks
Goat	21–22 Weeks	Rat	21–28 days
Hippopotamus	7½ months	Sheep	21–22 weeks
Horse	11 months	Whale	About 1 year

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. All the different kinds of things in the universe can be classified into three groups: things that are alive, things that were once alive, and things that never have been alive. Things that are alive and that were once alive contain organic compounds. Organic compounds contain the element carbon. Inorganic compounds lack the element carbon. Natural organic compounds were formed by living things. The earth's atmosphere, hydrosphere, and lithosphere are the chief sources of inorganic compounds.

2. There are four major phyla in the plant kingdom. The first phylum includes the bacteria, fungi, and algae; the second, the mosses; the third, the ferns; the fourth, flowering plants.

Plants that belong to the first three, or lower, phyla, usually live in wet or moist places. The bacteria, fungi, and algae lack roots, stems, leaves, and flowers. Mosses have rootlike appendages and the beginnings of stems. Ferns have roots, stems, and leaves.

The flowering plants are successful because they can live in a variety of habitats. Flowering plants have well developed roots, stems, leaves, supporting and conducting tissues which are adapted to the habitat in which the plant grows. Flowering plants have developed reproductive organs that enable the male cell (sperm) to reach the female cell (egg) without having to swim through water, or a film of water, as the male cells of ferns must. This method of reproduction also permits the flowering plants to reproduce in a variety of habitats.

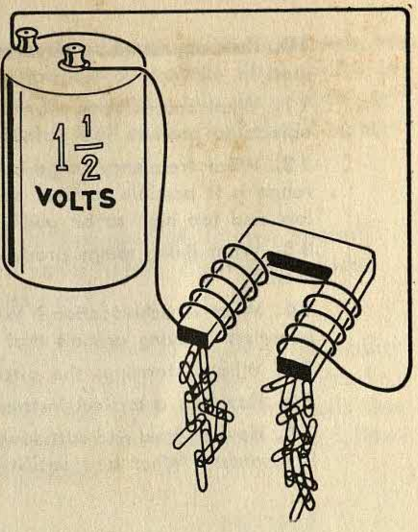
3. There are twelve major phyla in the animal kingdom. The protozoa, the lowest phylum in the animal kingdom, contains many different kinds of one-celled animals. One-celled animals live in the same kind of habitats in which bacteria, fungi, and algae are found. Most of the lower phyla, those animals without backbones, live in the water, in moist places, or in other living things.

One class of invertebrates, the insects, lives in many different kinds of places. Insects have a number of adaptations that make it possible for them to exist in every part of the world. Among these adaptations are their small size, variety of eating habits, and the changes they pass through from egg to adult.

Fish, amphibia, and reptiles are variable-temperature vertebrates. Some of these that live in the temperate zones become dormant during cold weather. Some estivate during dry or hot weather. Most kinds of fish lay eggs and do not care for their young. Most amphibia live near, and lay their eggs in, water or in moist places. Reptiles are more commonly found in low, hot, moist environments. Some kinds lay eggs; others hatch their young inside the female's body. Most variable-temperature vertebrates do not care for their young. Many of them shed their skins or molt as they increase in size.

Birds and mammals are constant-temperature vertebrates. They live in many different kinds of habitats. Most birds build nests, incubate eggs, and care for their young until they are almost fully grown. However, some birds can walk as soon as they hatch. Some birds migrate farther south in the fall and return to their breeding places in the spring. The cause of migration is unknown. Mammals give birth to, nurse, and care for the young until they are able to care for themselves.

The different classes of vertebrates can be identified by their outer coverings, their methods of locomotion, the habitats in which they live, and the amount and kind of care they give their young.



Chapter Sixteen

Forces and Energy

Making and Hearing Sounds

INQUIRIES

1. How many sounds can be recognized? Why can these sounds be identified?
2. What causes sound? In what way are all sounds alike?
3. How are things made to vibrate?
4. How do sounds differ?
5. Through what materials can sound travel? Through what materials does sound travel best?
6. When a sound is made at a distance, what do your eyes and ears record? Which travels faster—sound or light? How fast does sound travel through air? How fast does sound travel through other materials?
7. In what directions does sound travel through air?
8. How do people and some animals produce sounds in their throats? In what different ways do some other animals produce vibrations?
9. How do people and many kinds of animals hear sounds? In what unusual ways do some animals hear sounds?

10. How can sound be directed? What causes an echo? What kinds of materials are used to eliminate or control annoying echoes?

11. What causes some vibrating objects to produce high sounds and other vibrating objects to produce low sounds? What is *pitch*? What is *frequency*?

12. What frequency range is used to test the ability to hear? Through what frequency range is it *possible* to hear sound? What are the names of frequencies that are too low and too high to be audible?

13. What living things produce and hear ultrasonic sounds? How is ultrasonic sound used?

14. What is echolocation? What practical use has man made of echoes? Why are scientists studying animals that use echoes?

15. What determines the pitch of a vibrating mass?

16. How can a musical instrument produce so many musical notes?

17. How do loud and soft sounds differ? What is *intensity*? What is *amplitude*? What is *loudness*? What is a *decibel*?

1. How many sounds can be recognized? Why can these sounds be identified?

Improvise listening games and contests for identifying sounds. The children should not be able to see the objects that are making the sounds. At first use familiar classroom sounds, such as those made by opening and closing doors, raising and lowering window shades, running water, sharpening pencils, and tearing paper. Let pupils suggest many other ways to make sounds. They may want to hammer, saw, turn an egg beater, play rhythm instruments, play musical instruments, ring bells, bounce balls, blow horns and whistles, walk, run, skip, dance, clap, cough, sneeze, sing, and so on.

Help the children to record and identify on a tape recorder a long series of common sounds. Record, for example, sequences like these:

1. (a) The sound of a bouncing ball; (b) 20 seconds of silence; (c) a child's voice saying, "I bounced a ball."
2. (a) The sound of an egg beater; (b) 20 seconds of silence; (c) a child saying, "That was the sound of an egg beater."

Table 16.1

HOW VIBRATIONS ARE MADE

Striking	Blowing	Bowing or Rubbing	Plucking	Shaking
hammer	harmonica	saw	music box	tambourine
piano	accordion	violin	violin	castanets
xylophone	organ	skipping	guitar	
cowbell	whistle	dancing	cello	
electric bell	horn	sanding	banjo	
church bell	clarinet		harp	
drum	saxophone			
triangle	trumpet			
cymbals	trombone			
running	sneezing			
dancing				
skipping				
clapping				
marimba				
door knocker				
chimes				

Each child could be responsible for recording and identifying at least one sound. When the tape is rewound and played, the class will enjoy trying to identify each sound in the 20-second interval of silence before the recorded voice tells the answer.

Prerecord some unfamiliar voices and sounds. Enlist the aid of your school faculty, principal, secretary, visiting specialists and supervisors, school policemen, building custodians, and especially any new staff members whose voices the children may not yet have heard. Also, prerecord the sounds from some new noise-making toys. When this recording is played for the children, tell them to listen carefully to these unknown sounds and voices because they may hear them again some day soon. Casually introduce these new toys and people into the children's daily experiences. Matching the sound of a new toy to its recorded sound and the new voices to those on the tape recorder will be a challenging task for the children.

Discuss with the children the reason why they can identify many different sounds.

2. What causes sound? In what way are all sounds alike?

Provide many simple experiences for children to observe what always happens when a sound is made. In discussing their observations, help them to understand that it is *only when objects move to-and-fro rapidly that they cause sound.* In this way, all sounds are alike. Introduce the word *vibration,* which describes the rapid to-and-fro motion that produces sound.

3. How are things made to vibrate?

Have the children again make sounds with all kinds of objects. Each time ask, "What did you do to cause the vibration?" Help them to realize that most of the many ways in which they produced sounds can be described simply as 1) *striking,* 2) *blowing,* 3) *rubbing or bowing,* 4) *plucking or picking, and* 5) *shaking.*

4. How do sounds differ?

Help the children to classify sounds as either loud or soft, high or low, music or noise. An infinite variety of listening experiences can be invented in the form of games. The ability to hear, distinguish, and reproduce these opposites can be integrated with music and music appreciation.

5. Through what materials can sound travel? Through what materials does sound travel best?

Encourage the children to explore the ability of different solids, liquids, and gases to conduct sound. See Figs. 16.1 and 16.2 for methods that can be used to test these substances. The following list is suggestive:

1. air
2. alcohol
3. antifreeze
4. brick
5. ceiling tile
6. ceramic tile
7. chalkboards (slate, metal)
8. chalk trays (wood, metal)
9. cloth
10. concrete
11. desks
12. ditto fluid
13. doors
14. flannel boards
15. floors
16. glass
17. ice
18. linoleum
19. oil
20. plaster
21. plastic
22. radiators
23. soil
24. steam
25. stone
26. string
27. wallboard
28. water
29. window poles
30. yardsticks

During this free exploration, watch for evidence that the children are beginning to discover the need for controls. A few pupils may try to compare the *same sound* heard through *equal distances* in different materials. Others may try to control the *loudness* of the sound. When these first free attempts to control the experiment occur, call the class together for a discussion. Point out the individual controls that specific children have tried. Discuss why controls are needed to find out which materials are the *best conductors* of sound. Emphasize the need for comparing sounds that travel through *equal distances.* Help them to agree upon one sound generator, which produces a *controlled loudness* that they can use in their experiments. The ticking of either a pocketwatch or a man's wristwatch makes a good *controlled source of sound.* The selection of a unit of measurement will depend upon the size of the containers that are used to test the conduction of sound through air (a gas)

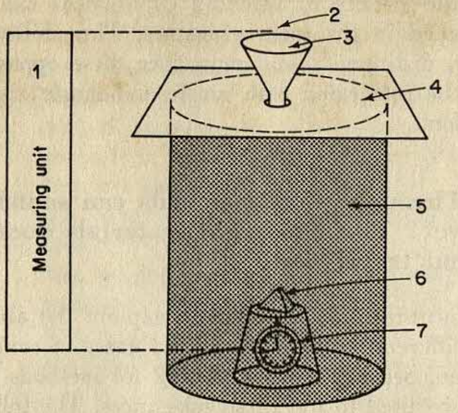
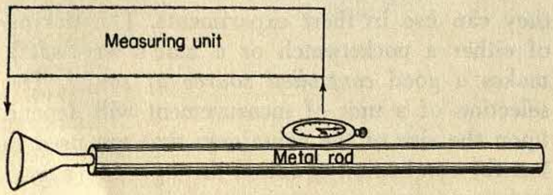


Fig. 16.1 Simple equipment for testing, measuring, and comparing the ability of gases or liquids to conduct sounds. (1) Cardboard measure equal to distance from ear to watch; (2) ear to be pressed against top of funnel; (3) funnel inserted through cardboard; (4) cardboard cover; (5) glass container filled with gas or liquid to be tested; (6) a weight; (7) pocket watch attached to inside of inverted glass tumbler of air to prevent watch from getting wet when ability of water to conduct sound is being tested.

and through a liquid. If the children set up an experiment as shown in Fig. 16.1, they will construct a *simple cardboard measuring unit.* This measuring unit can be used for comparing the differences in the ability of gases and liquids to conduct sound. After the pupils have measured the distance from the top of the funnel to the middle of the watch in the glass container, have them use this same measuring unit in each of their experiments. The use of the same measuring unit serves as a control factor. What is controlled? (The distance through which the sound is heard.)

Figure 16.2 shows a way to use the cardboard measuring unit to compare the conduction of sound through solid materials that are longer than one measuring unit.

Fig. 16.2 Simple equipment for testing, measuring, and comparing the ability of solids to conduct sounds. Press ear against funnel and listen to the tick of the watch which has traveled through one measuring unit (use the cardboard unit prepared in Fig. 16.1).



Help the class collect a variety of materials they can test. Also, help them to plan a rating scale they can use to compare the difference in the ability of these materials to conduct sound. The terms *excellent, very good, good, poor,* and *very poor* may be used. Ask several children to organize a chart similar to the one in Table 16.2.

During the planning period, discuss why it is important to *limit* the changes in the testing procedures to the *differences* in the material that is being tested. Point out that if they use a funnel when they test the conduction of sound in liquids (see Fig. 16.1), they should use the *same funnel* to test other materials. The controlled source of sound—the ticking of the watch—should always be listened to through the funnel. The funnel should always be *one measuring unit* away from the sounder. (See Fig. 16.2).

When the pupils are ready to test the conduction of sound through liquids, have them practice the technique of lowering an *inverted* glass tumbler into the bottom of the container when the container is partially filled with water. (The tumbler should be held securely in a perpendicular position and be held firmly against the bottom of the container.) Substitute a crushed *facial tissue* for the watch during this practice period. When pupils can place the inverted tumbler on the bottom of the container and lift the tumbler out again, without getting the tissue wet, they are ready to test liquids with the watch (see Fig. 16.1).

Each material should be tested several times and the majority of the class should agree upon the rating that is to be given the material. When all of the materials have been tested and the results recorded on the chart, have the class summarize the results of their experiment.

In their reading, the pupils may discover that sound does not travel in a vacuum. They may also find an experiment similar to the one that follows, which is used to prove this. A bell is placed inside a glass jar from which the air can be pumped. Either an alarm clock or an electric bell is used. If your school has equipment for performing this experiment, help the children do the experiment. If not, make arrangements with the high school science department for your class to see the experiment. It should be possible

Table 16.2

A COMPARISON OF THE ABILITY OF DIFFERENT KINDS OF SOLIDS, LIQUIDS, AND GASES TO CONDUCT SOUND

State of Matter	Excellent	Very Good	Good	Poor	Very Poor
Solid	metals	wood ice		soil clay paper glass plastic sand	book cardboard linoleum cement rubber cotton cloth sawdust
Liquid		water alcohol antifreeze vinegar			
Gas			air		

for you to take the class to their laboratory, or for some of the high school students to bring the equipment and do the experiment in the classroom.

6. When a sound is made at a distance, what do your eyes and ears record? Which travels faster—sound or light? How fast does sound travel through air? How fast does sound travel through other materials?

Take a large drum and a drumstick outdoors. A metal pail and a stick can be used in place of the drum and drumstick. Station one child with the drum on the sidewalk as far as a block from the rest of the class. Have this child raise the drumstick and hit the drumhead once. Ask the children, "What is the difference between what you see and hear?" (They will see the child strike the drum before they hear the sound of the drum.)

Have the pupils look up the velocity of both light and sound. (Sound travels 1100 *feet* per second through air at 0°C or 32°F. Light travels about 186,000 *miles* per second.)

Discuss with the class why they hear the thunder from distant lightning *after* they see the flash of lightning. If the lightning is 9 miles away, the light from it would travel to an observer 9 miles from it in about 20-thousandths of one second (1/20,000 of a second). It would take the sound of the thunder caused by this flash of lightning about 43 seconds to travel the same 9 miles. At 1100 feet per second, it takes nearly 5 seconds for sound to travel one mile. Explain to the students how they can roughly estimate how far away a flash of lightning occurs by slowly counting from the time the flash is seen until the time the thunder is heard. When the thunder is heard at the count of 5, the sound has traveled about 1 mile; at the count of 10, 2 miles, and so on. Encourage some of the pupils to work with the mathematics involved in the illustration. The class should also understand that this explains why the sound and the sight of lightning occur closer and closer together as the distance between the lightning and the observer becomes smaller. Discuss with them why lightning sometimes seems to have no thunder accompanying it. (The sound occurs too far away to be heard.)

Ask the group to consider why the sound from high, fast flying jets seems to come from a place that is far behind the jet which is making the sound. (Many jets fly faster than the speed of sound.)

Ask some of the pupils to look up the comparative speed of sound transmitted through some liquids and solids. They will find that sound travels approximately:

4 times faster through water than through air;
10 times faster through wood than through air;
15 times faster through iron than through air;
17 times faster through aluminum than through air;
20 times faster through glass than through air;
$\frac{1}{5}$ as fast through rubber as through air.

7. In what directions does sound travel through air?

Ask the class to devise an original experiment to discover in what directions a sound travels from the source through air. When pupils have demonstrated that sound moves outward in *every direction* from the source of the sound, help them to visualize this spread of sound through air as an expanding sphere with the source of the sound at its center.

Next ask them to produce two sounds at the same time in different areas of the room. If the spread of both sounds could be seen, visualize how they would look when each spreads out from its source, meets, and passes through the other. Finally, try to visualize the spread of the many sounds that can be present in one room at the same time. It is worth the time to encourage children to use their originality to picture this concept on a bulletin board.

Borrow a tuning fork and show children how to start its two prongs vibrating by hitting the end of one prong with a rubber mallet. Let them hear, see, and feel the vibrating prongs. Then have them hold the tuning fork so the two vibrating prongs lightly touch the surface of water in a large pan. Ask them to describe what the vibrations of the tuning fork do to the surface of the water. (They cause *visible waves* that begin at the vibrating tuning fork and spread out in circles over the surface of the water to the edges of the pan.) Ask what they think starts each single wave. (Each vibration of the tuning fork.) Why are there a succession of waves as long as the tuning fork continues to vibrate? (Each vibration starts a new wave.)

Ask students what they think the vibrations of the tuning fork do to air. (They cause a succession of *invisible waves.*) What have scientists named such waves? (Sound waves or compression waves.) How can sound waves moving through air be visualized? (Sound waves in air spread outward from the source of sound in all directions. They move outward like an expanding sphere. Vibrating molecules set other molecules which they *contact* in vibration. Sound waves continue to travel outward in all directions so long as the vibrating molecules have enough energy to set the molecules which they contact in vibration.)

8. How do people and some animals produce sounds in their throats? In what different ways do some other animals produce vibrations?

Suggest to the children that they compile a list of animals, including man, that they can observe making sounds. For variety the list should include many of the following: man, dog, cat, canary, parakeet, toad, frog, fly, chameleon, cricket, bee, cow, horse, beaver, click beetle, and katydid. From this list, allow each child to select an animal for an intensive study of its method of producing sound. Suggest that, if they make proper containers for housing small animals like toads, frogs, flies, and crickets, they can bring these animals into the classroom for observation (see Chap. 12). Remind them that television can be most helpful for observing people singing and talking. The zoo programs on television would also be helpful for observing animal sounds. If you have a movie library, allow the pupils to select the animal films which they think would be helpful.

Explain that careful observation would include not only *hearing* the sound but also *watching* the production of the sound and, whenever possible, *feeling* of the area where the sound is being made. Suggest, too, that they keep detailed notes of what they observe.

After their *observations* are completed and recorded let them *read* their reference and science books. The pupils should be able to find information similar to that given in Table 16.3 and Fig. 16.3. As a last step, the pupils should prepare and share their knowledge by *reporting* their findings to the class in the most interesting, dramatic, visual, and original ways possible. The use of pets, small animals, charts, models, and experiments should be encouraged.

Their reports should include a knowledge and recognition of the different sounds made by cats and dogs. Children are familiar with the cat's:

Table 16.3

HOW DIFFERENT BODY PARTS ARE USED TO PRODUCE SOUND

Kind of Animal	Body Part Commonly Used	How Sound Is Produced
Vertebrates		
Mammals	voice box (larynx) palate tongue lips teeth lungs throat, head, and chest cavities abdomen	The voice box (larynx) in humans is located in the *upper* part of the windpipe (trachea). See Fig. 16.3. Two thin sheets of membrane (vocal cords) in the larynx vibrate when air from the lungs is forced between them. When a person speaks, throat muscles that are attached to the vocal cords contract and pull the cords closer together. When air rushes through this narrow opening, the cords are set in vibration. The vibrations of the cords cause the resonators (hollow cavities) in the chest, throat, and head to vibrate. These resonators reinforce and direct the vibrations to the mouth and produce the quality of sound that makes it possible to recognize one voice from another. Humans learn to use the lips, tongue, and teeth to control, modify, and produce variety in the sounds they make. Most other mammals are known to have voices too (use a voice box to make certain sounds). They do not make the variety of sounds that humans do. This may be because they use their lips, tongue, and teeth less or it may be because their need for communication is limited to producing sounds that convey to other animals warning and distress signals or sounds that portray to other animals their feelings and desires.
Birds	voice box (syrinx) palate tongue lungs throat, head, and chest cavities	Birds have a special voice box called the *syrinx*. It is located at the *lower* end of the trachea. The syrinx and the tongue are used mainly to produce different tones. Throat, head, and chest cavities are used, as in mammals, as resonators. Birds sing more during the mating season. It is believed that the male bird's song serves the dual purpose of attracting the female and/or warning other males to stay away from its breeding area. Each species of bird sings one song that is characteristic of its kind. The *rhythm* and *pitch* of the song is believed to be an inherited trait. The *quality* of the song is probably learned by imitation. It is known that the song of birds raised in captivity is improved in quality when they are released and allowed to associate with other birds of their kind. Like mammals, birds also make sounds that convey warning and distress signals to other birds.
Amphibians	tongue lungs throat, head, and chest cavities voice box	When a bullfrog croaks, he opens his mouth, inflates his throat by gulping air, and vibrates the end of his tongue as well as his vocal cords. Other amphibians produce sound in a way that is similar to a bullfrog's, but the sound is less boisterous and not so frequently recognized by people.
Reptiles	lungs throat and cheek muscles voice box	Reptiles that make sound emit hisses, croaks, snorts, snuffles, and roars by expelling air from their lungs and alternately expanding and contracting their throat and cheek muscles. The *American bull alligator* and the *South American Caiman crocodile* are the noisest of the reptiles. Their bellows are most frequently heard during the mating season. The *South American lizard*, commonly called the gecko, is also

Table 16.3 (*cont.*)

Kind of Animal	Body Part Commonly Used	How Sound Is Produced
		famous for its mating call, "gecko, gecko," which it emits from the safety of the entrance to its burrow in a hillside. Male *chameleons* blow out their brightly colored throat ruffs and emit squeaking sounds when they are startled and, also, when they are searching for a mate. Some kinds of *turtles* have true voices (voice boxes).
Fish	teeth swim or air bladder	Fish have no vocal cords, but they do make sounds by grinding their teeth and setting up vibrations in their swim or air bladder. Sensitive underwater listening devices have detected beeps, croaks, grunts, and groans made by different kinds of fish. Some croaks are believed to be mating calls. Other sounds may be warning signals that are passed back and forth between the members in a school of fish.
Invertebrates		
Insects	legs thorax abdomen wings	Insects are actually voiceless because they do not have voice boxes. But, they do produce a variety of sounds with such parts of their bodies as their legs, thorax, abdomen, and wings. Insects that do produce sound either drum (stridulate), creak, or make a buzzing with their wings. The creaks and stridulations are made during the mating season and to frighten away other animals. *Male crickets* produce sound by rubbing together their wing covers. *Short-horned grasshoppers* and *locusts* rub the spines on the inner side of their jumping legs across a thickened ridge on their fore wing. *Long-horned grasshoppers*, such as *katydids*, rasp the spines on their forelegs together. *Cicadas*, sometimes called *17-year locusts*, have a pair of large drum heads on both sides of the abdomen. Muscles connected to the drum heads alternately contract and expand causing the drum heads to vibrate. Almost all *moths* are silent. Some, like *hawk moths* and *hummingbird moths*, make a whirring or a buzzing sound when they are in flight. *Flies*, *bees*, and *mosquitoes* produce either a whirring or a buzzing sound with their wings when they are in flight.
Crustaceans	claws	Many crustaceans live on land and not much is known about what sounds they may make. More is known about the sounds made by the crustaceans that live in the sea. Sensitive underwater sound devices, like sonar, which are used to detect the sound of submarines and to map the ocean floor, also have detected many different kinds of sounds made by marine life. Sound detectors have "picked up" the grunts, whistles, rattles, pops, and snaps made by many kinds of marine life. One kind of *shrimp*, called the "*snapping shrimp*," makes a sound loud enough to "trip off" underwater listening devices. The snapping shrimp makes its loud snaps by rapidly opening and closing its claws.

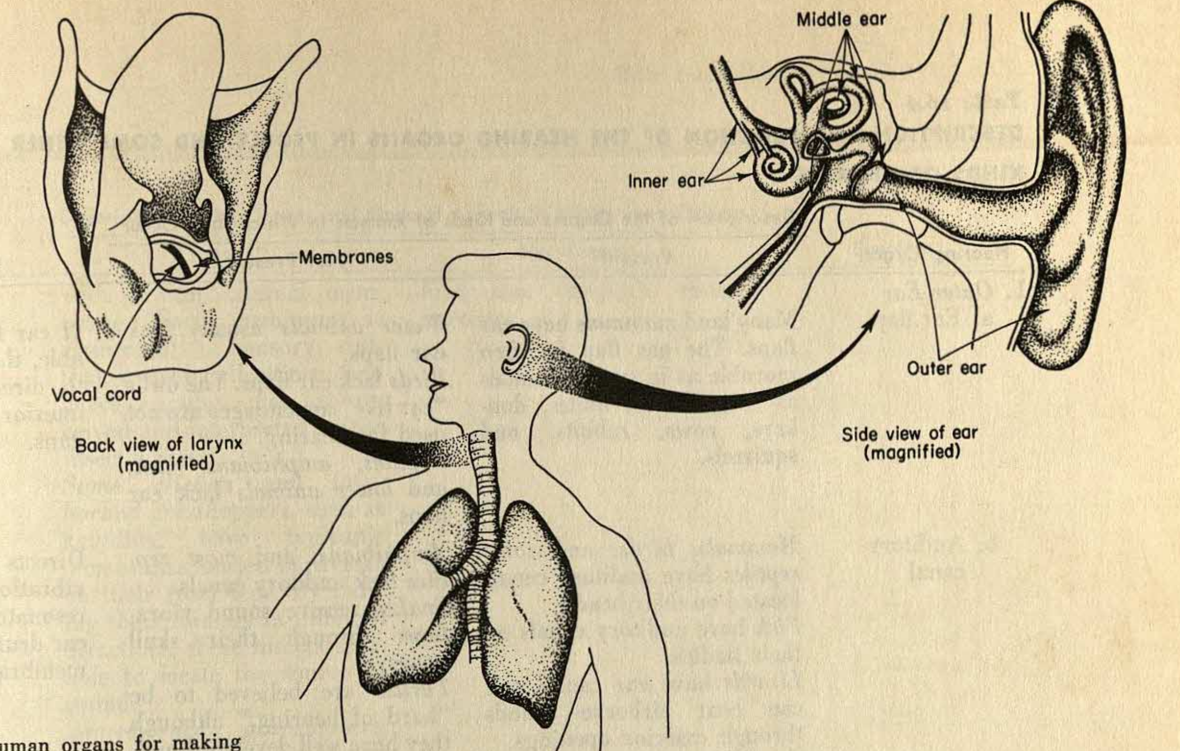


Fig. 16.3 Human organs for making and receiving sound.

(1) *purring*, a sound expressing the cat's *feeling* of contentment; (2) its *meow*, a sound it uses when it wants to come in or go out and when it wants food; (3) its *hissing* and *spitting* sound, when it is annoyed or angered; and (4) its *loud distinctive mating cry*, often heard outdoors at night. Children are also familiar with the dog's: (1) *bark* used when it wants food, to enter or leave the house, and when the dog is playing; (2) its *growl*, a warning sound, meaning stay away; (3) the *yipping* sound a dog makes when it is hurt; and (4) the *snapping* sound a dog makes when it is startled and protecting itself. Encourage the children to describe, in their own words, these different common cat and dog sounds; help them to associate these sounds with the animal's attempt to convey warning and distress signals, and to portray its feelings and desires.

The children's reports could be made interesting by including: (1) the beaver slapping his flat tail on water; (2) the rattlesnake shaking the rattles on *his* tail; (3) the grouse drumming with its wings; and (4) the woodpeckers hammering with their beaks. Woodpeckers hammer on trees when they are seeking grubs to eat, and when they are excavating a hole for a nest. During the mating season, they have been observed hammering not only on trees and wood, but also on metal, trash barrels, roofs, and glass panels in ornamental yard lights.

9. How do people and many kinds of animals hear sounds? In what unusual ways do some animals hear sounds?

When the children work with these inquiries, they should use the same three-step method—(1) observing, (2) reading, and (3) reporting—as described in Inquiry 8.

The list of animals they study should include many of these: man, dog, bird, fish, grasshopper, cricket, rabbit, cat, and frog. (See Table 16.4 and Fig. 16.4.) In addition, encourage the pupils to use the microscope and microprojector when studying and reporting to the class on the hearing organs of fish, grasshoppers, and so on.

10. How can sound be directed? What causes an echo? What kinds of materials are used to eliminate or control annoying echoes?

Roll three or more sheets of newspaper into a shape like a megaphone. Take the class out-

Table 16.4

DESCRIPTION AND FUNCTION OF THE HEARING ORGANS IN PEOPLE AND SOME OTHER KINDS OF ANIMALS

	Description of the Organs and Kinds of Animals in Which They Occur		
Hearing Organ	**Present**	**Not Present**	**Function**
1. *Outer Ear*			
a. Ear flap	Many land *mammals* have ear flaps. The ear flap is often movable as in such mammals as cats, horses, mules, donkeys, cows, rabbits, and squirrels.	*Water animals* usually lack ear flaps. *Birds* lack ear flaps. The owl's "ear like" appendages are not used for hearing. *Reptiles, amphibians, fish,* and *lower animals* lack ear flaps.	If ear flaps are movable, their function is to direct sound into interior hearing organs.
b. Auditory canal	*Mammals, birds,* and *some reptiles* have auditory canals located on their heads. *Fish* have auditory canals on their bodies. *Lizards* have ear canals and can hear airborne sounds through exterior openings. *Crocodiles* have ear openings that are protected by valves that close when the crocodile swims underwater. *Fish* have an auditory canal, called the lateral line canal, extending along both sides of their bodies. They are believed to be capable of "sensing" vibrations (changes in pressure) in water (see Fig. 16.4). The lateral line canal is actually a fold in the skin.	*Amphibians,* and *most reptiles* lack auditory canals. *Snakes* receive sound vibrations through their skull bones. *Turtles* are believed to be "hard of hearing," although they have well developed middle and inner ears. They may receive vibrations of low frequencies from both the ground and water. *Some insects* receive vibrations through sensitive hairs or spines located in various parts of their bodies; other insects receive vibrations through a series of air pipes located along the sides of their abdomens (see Fig. 16.4); and others, through tympanic membranes located on abdomen or forelegs.	Directs and reinforces vibrations (acts as a resonator) that cause ear drum or tympanic membrane to vibrate.
2. *Middle Ear*			
a. Ear drum or tympanic membrane	*Mammals, birds, reptiles, amphibians,* and *some insects* have ear drums or tympanic membranes. *Crickets, grasshoppers, locusts, cicadas,* and the *majority of moths* have ear drums but they are located either on the legs or abdomen and are connected to the insect's breathing apparatus. Insects breathe through a system of air pipes that extend through their bodies. A pair of these air pipes, one located on each side of the body, widen into air pockets that are covered	*Some insects* lack tympanic membranes. Instead they have either external sensory hairs or spines that are stimulated by vibrations in air or water. The sensory cells on the end of the *cricket's* abdomen react to vibrations from both the air and the ground. The *whirligig beetle* avoids obstacles in the water by the wave echoes it receives through its antennae (see Fig. 16.4). Maybe *mosquitoes* also react to echoes received by similar kinds of sensory cells.	Vibrations from air "set" ear drums or tympanic membranes in vibration.

	Description of the Organs and Kinds of Animals in Which They Occur		
Hearing Organ	Present	Not Present	Function
	with a thin external membrane. Each membrane is connected to sensory cells that convert vibrations into nerve impulses that are received and interpreted by the insect's brain. *Some crickets* and *long-horned grasshoppers,* such as katydids, have tympanic membranes located in cavities on their front legs. By moving their forelegs in different directions, these insects seem able to locate the source of sound. *Short-horned grasshoppers,* such as Carolina, American, and meadow locust, have tympanic membranes located on the abdomen (see Fig. 16.4).	*Fish* lack tympanic membranes.	
b. Conducting bone	*Mammals* have three conducting bones—the hammer, anvil, and stirrup (see Fig. 16.3). *Birds and reptiles* have a single rod-like bone in the middle ear. Most kinds of *frogs* have 2 bones in the middle ear.	*Fish and insects* lack a conducting bone or bones. *Insects* respond to sound vibrations received by either hair cells or spines located in breathing tubes.	The bone or bones in middle ear are set in vibration by ear drums or tympanic membranes.
3. *Inner Ear*	*Mammals* have an oval window (thin membrane) that connects middle ear to the inner ear. The inner ear contains hollow canals filled with a liquid. These canals are called (1) the semicircular and (2) the cochlea. The canals contain sensory cells that are stimulated by sound vibrations. It is believed that different sensory hair cells react to different sound frequencies. *Birds, reptiles, amphibians,* and *fish* have inner ears similar to mammals'.	*Insects* lack an inner ear. Sensory cells that stimulate auditory nerves in insects are located either in external hair cells, spines, or in breathing tubes.	The oval window receives vibrations from the stirrup bone in the middle ear. The vibration of the membrane in the oval window sets up vibrations in the liquid in the hollow canals of the inner ear. The cochlea is separated into a lower and upper gallery by a thin membrane. This membrane contains thousands of tiny fibrous sensory cells that connect with the auditory nerve.

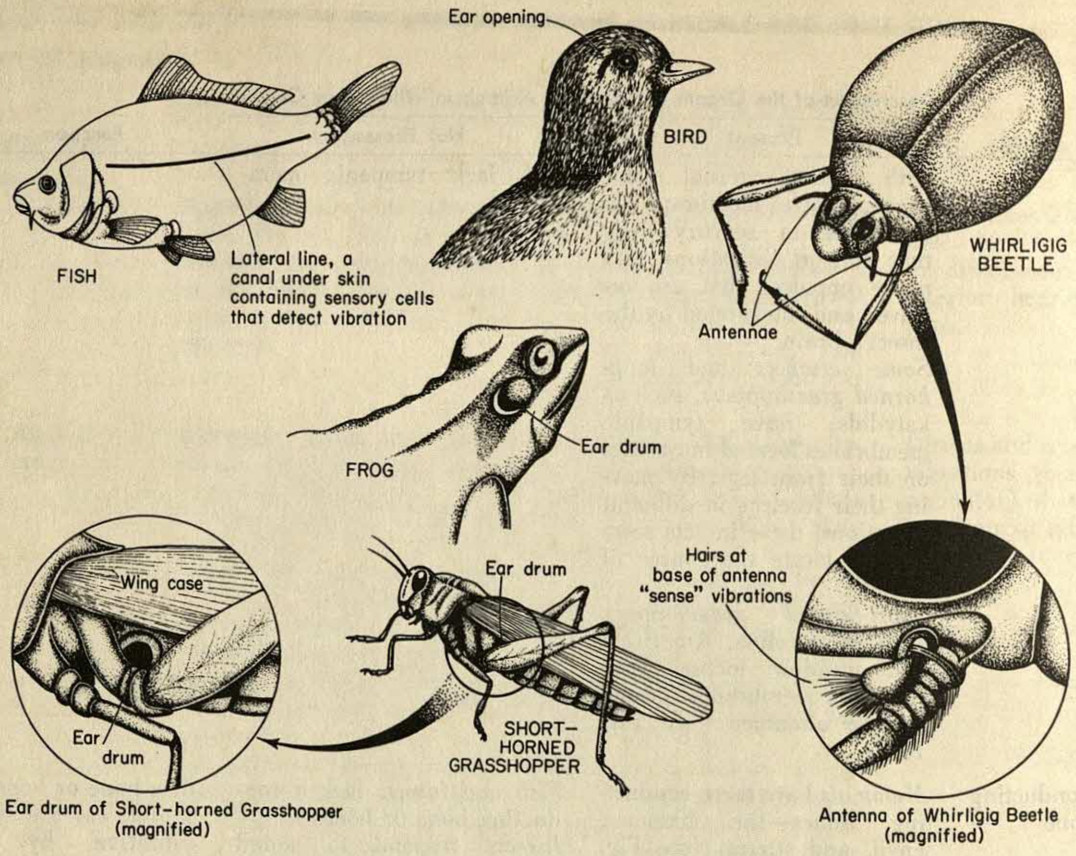

Ear opening
BIRD
FISH
Lateral line, a canal under skin containing sensory cells that detect vibration
WHIRLIGIG BEETLE
Antennae
FROG
Ear drum
Wing case
Ear drum
Ear drum
SHORT-HORNED GRASSHOPPER
Hairs at base of antenna "sense" vibrations
Ear drum of Short-horned Grasshopper (magnified)
Antenna of Whirligig Beetle (magnified)

Fig. 16.4 Hearing organs of different kinds of animals.

doors and arrange them in a large circle. A student in the center should direct this megaphone to one person in the circle and speak through it in a normal tone of voice. How many students can hear the words spoken? Adjust the size of the circle until only those few students facing the megaphone can hear. Repeat until all have observed that the sound waves are directed into a controlled path by the shape of the megaphone.

Have two pupils stand at the center of the circle. Ask one to hold the megaphone to his ear. As different children in the circle speak softly, ask the two in the center to turn and listen. Why is the pupil using the megaphone able to hear when the control pupil cannot? (The large open end of the megaphone collects and directs more sound waves into the ear.) Ask the class to plan a controlled method for testing whether increasing the size of the outer ear, by cupping their hands around the ear or by adding large paper ears, helps them to hear soft sounds. (It does.)

Discuss how large ears and ears that can be moved toward the direction from which the sound is coming help animals to hear. Collect pictures of animals with large ears. Watch robins hunt for worms. Why do they tilt their heads? Conceal a dog's squeaky toy from him; watch how he turns his head until he points his ear in the direction from which the sound is coming to him. Watch a rabbit swivel its ears in the direction of the sound.

Obtain a 100-foot length of garden hose. Stretch it from your classroom to another classroom. Put funnels in both ends. Have the children use it as a speaking tube to communicate from one room to the other. Try communicating without the hose. Discuss apartment house speaking tubes that connect the apartment with the lobby. Find out how many children have seen movies of naval officers using a speaking tube to communicate with men in other parts of the ship. Discuss why modern ships still have speaking tubes as well as telephones. Discuss how the garden hose and speaking tubes conduct and direct the sound waves through the columns of air inside of them. Borrow a doctor's stethoscope. Observe that it operates upon the same principle.

Have the children build a string and paper cup "telephone." To the "main line," attach two or three "party lines." When these "party lines" are stretched at different angles away from the original line, why can the listeners eavesdrop on the main line conversation? (The vibrations sent down the main line also follow the connected lines.) Make certain that the children understand that the wires connected to a real telephone *do not* carry sound waves as the make-believe string and paper cup phone does. (See Chap. 19, Inquiry 4.)

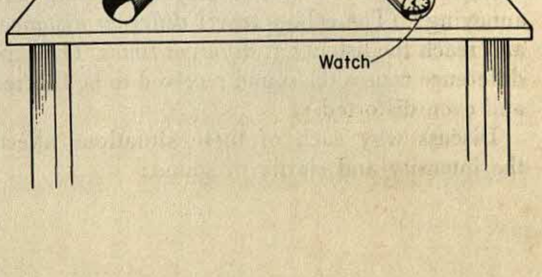
Arrange two cardboard mailing tubes as in Fig. 16.5. Lay a watch at *A* inside tube No. 1. At the *A* end of tube No. 2, listen for the tick of the watch. About an inch back from the *B* ends of the two tubes, place upright a hard smooth material such as glass or metal. Listen at the *A* end of tube No. 2 again. Why can you now hear the tick of the watch? (The hard smooth material *reflects* the sound waves received from tube No. 1 into and down tube No. 2.)

Find an outside wall of your school that is unbroken by doors or windows. With a megaphone, shout at this wall, from a measured distance of more than 55 feet. Why do you hear an echo? (The shouted sound is reflected from the wall back to your ears.) Why should you stand more than 55 feet from the reflecting surface? (Sound travels at about 1100 feet per second. When you stand at a 55-foot distance, sound travels 55 feet to the wall and 55 feet back to you, a total of 110 feet. Because 110 feet is $\frac{1}{10}$ of 1100 feet, this echo occurs $\frac{1}{10}$ of a second after the sound is made. Echoes from a reflecting surface at 55 feet or less come back in $\frac{1}{10}$ of a second or less. This is too fast for the ear to separate and distinguish between the original and reflected sounds. The most spectacular echoes occur when sound is reflected from distant surfaces. It is then that the echo occurs enough later to be a distinct and dramatic sound.) Discuss how mountains, cliffs, canyons, and bodies of water reflect sound to cause echoes. Map the location of places in your area where echoes can be produced. Determine what the reflecting material is, in each place. Read about and discuss why certain places in the world are famous for multiple echoes. Sometimes as many as three or more echoes of the same sound are heard in these places. Why are the different echoes heard at different times? (There is more than one reflecting surface. Because these sound reflectors are at different distances, the reflected sounds return at times determined by the distances they travel.)

Ask one of the pupils to hold a metal pail before his face. Tell him to shout into it and then lower the pail. Ask him to shout again at the same intensity. Why did his voice sound louder to him when he shouted into the pail? (The pail reflected the sound. Because the distance the sound traveled to the bottom of the pail and back to the ear was small, the echo occurred so fast it blended with and added to the original sound. The combination of the two made the sound recorded by the ear seem louder.) Why do people enjoy singing in the bathroom? (The room is usually small. Often the floor and some of the walls are tiled. The fixtures are made of hard smooth materials. Because there are many sound reflectors close to the singer, the multiple echoes which are produced almost simultaneously with his voice make his voice sound stronger and louder to him.)

Let the pupils who are interested read, report, and explain to the class why certain *oval* dome-shaped rooms (like the Hall of Statues in the

Fig. 16.5 Sound waves traveling through cardboard tube 1 can be reflected through tube 2.



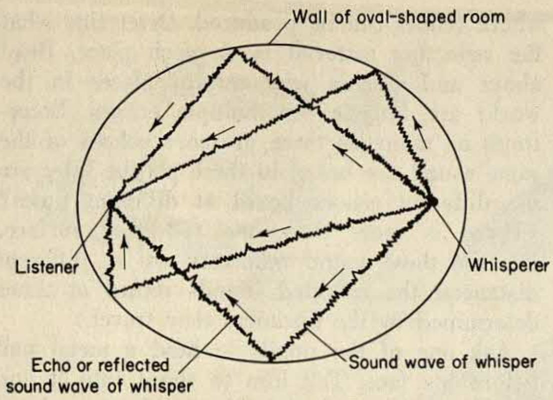


Fig. 16.6 In a room with walls curved in the shape of an ellipse, the many reflected sounds heard by the listener have all traveled equal distances from the whisperer to the listener. Therefore, all these echoes arrive at the same time and cause amplification by reinforcing each other.

Capitol in Washington, D. C. and Saint Paul's Cathedral in London) are famous as whispering galleries. (In these rooms a listener, standing at one particular place in the room, simultaneously receives many echoes from the person who whispers from another designated place in the room. These multiple echoes added together produce a clear audible sound many feet away. (See Inquiry 1, Chap. 25, and Fig. 16.6.)

Discuss why shell-shaped structures are used behind bands and orchestras.

Repeat the mailing tube experiment. Substitute softer and more spongy materials for the smooth, hard material that reflected the tick of the watch. Which of these new materials are the best sound absorbers? (The softer, more spongy ones are.)

Line your metal pail with a soft blanket. Why does shouting into it now not increase the sound you hear? (There are no echoes to reinforce the sound, because much of the sound which reaches the blanket is absorbed instead of reflected.)

Discuss why hard-surfaced walls, ceilings, and floors in conventional-shaped rooms produce multiple echoes. Why are they distracting and annoying? (The echoes travel *different distances* and reach the listener at *different times*. The time difference causes the sound received to be blurred and even distorted.)

Discuss why each of these situations affects the intensity and clarity of sound:

1. Auditoriums commonly have velvet curtains for windows and stage.
2. Auditoriums often have upholstered seats.
3. The sound of an orchestra, in an auditorium full of people, is more pleasant than in an empty auditorium.
4. Rooms with rugs, upholstered furniture, window curtains, and draperies seem quieter than empty rooms.
5. Ceiling tile is called acoustical tile.
6. Automobile mufflers muffle sound. (Open and examine an old discarded muffler to see how the sound is muffled.)
7. School buildings are built to muffle noise.

11. What causes some vibrating objects to produce high sounds and other vibrating objects to produce low sounds? What is pitch? What is frequency?

Obtain a number of tuning forks that produce both high and low tones. Let each child vibrate the tuning forks, hold the prongs close to his ear, and listen. Let the class decide which fork produces the lowest tone, and which produces the highest tone. Ask the pupils to watch the prongs as both forks vibrate. What difference in vibration can be seen? (The prongs of one fork vibrate faster than the prongs of the other.) Allow them to touch lightly the vibrating prongs of each fork. What difference in vibration can be felt? (One vibrates faster than the other.) Which vibrates faster? (The one with the higher tone vibrates faster.)

Explain to the children that the word *pitch* is used to describe the difference between high sounds and low sounds. *Pitch* refers to the highness or lowness of sound.

Ask the class to listen while you sound all the notes on a pitch pipe, and to raise their hands when they hear the highest pitched note, and the lowest pitched note. Discuss why it is called a *pitch* pipe.

Again have the children listen to, and watch, the two vibrating tuning forks. Ask them what determines the difference in pitch. (Slow vibrations produce a low pitch and faster ones, a higher pitch.)

Help pupils to understand that, when one vibration speed is compared with another, a standard unit of time is used. Use some of these comparisons as illustrations:

Automobile #1 goes	10 miles per hour
Automobile #2 goes	60 miles per hour
Airplane #1 goes	200 miles per hour
Airplane #2 goes	300 miles per hour
Jet #1 goes	500 miles per hour
Jet #2 goes	800 miles per hour
Astronauts orbit the earth at about	17,000 miles per hour

Next, compare the speed of sound with the speed of light.

Sound travels about	1100 feet per second
Light travels about	186,000 miles per second

Even though sound is measured in *feet* per second and light in *miles* per second, the time control used for comparing their speed is *one second.*

Ask the students if they think the pitch of the two tuning forks should be compared by the number of vibrations per hour, per minute, or per second. Help them to decide which unit of time—one hour, one minute, or one second—would be most sensible to use for comparing the number of vibrations of the two tuning forks. (Because they vibrate so fast, one second would be more useful than one minute or one hour.) Explain that the *number of vibrations per second* determines the pitch and is known as the *frequency* of the vibrating object. The *frequency* of a vibrating object is the number of times it vibrates each second.

Ask the children to examine both tuning forks to see if their frequency is stamped on them. If there is a number on a tuning fork, it is the number of vibrations per second, or frequency, of the fork.

Ask the children to listen to the change in pitch as you sound each note from left to right on the piano keyboard. How many different frequencies can the piano make? (As many as there are keys.) Show the children the strings inside the piano that vibrate when a key is struck. Cause the strings that have the lowest and highest pitch to vibrate. Let the children touch their fingers lightly to these vibrating strings. They will be able to feel the difference in the frequency of the vibrations.

Obtain two tuning forks with two different frequencies. Firmly attach a needle to one prong of each. Smoke a piece of glass in a candle flame. Lay the glass with the smoked side up on a larger sheet of paper. Cause both forks to

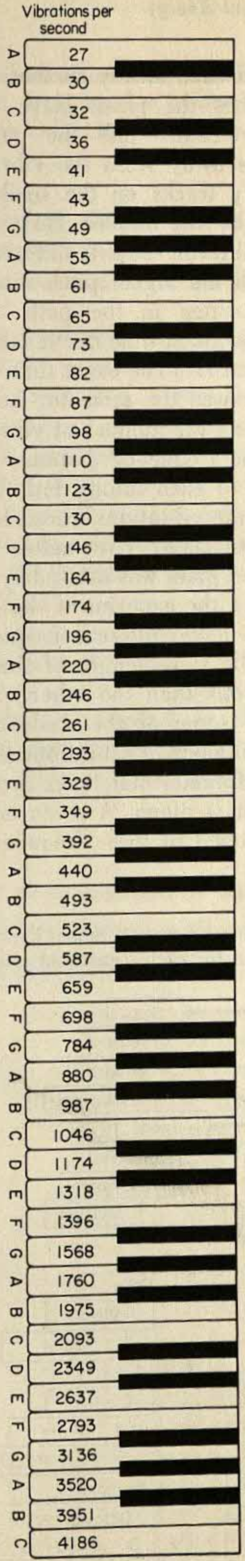


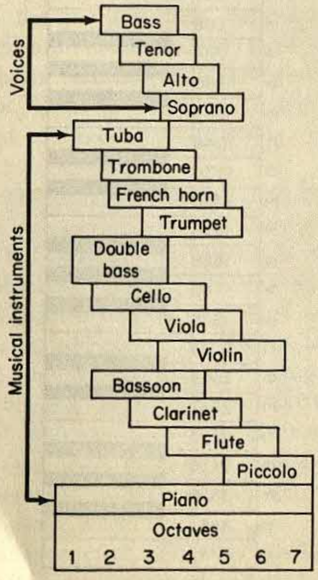
Fig. 16.7 Piano frequencies (American standard).

vibrate. Hold each steady so that the needle on it just touches the glass. Have a third child slowly and steadily pull the paper with the smoked glass away from the vibrating needles. See the wavy tracks on the smoked glass that were traced by the needles. How are the tracks of the two vibrating objects different? (The tuning fork with the higher pitch made more back and forth swings in the path traced by its needle.) How much time did it take each needle to trace its path? (The exact time is not known, but the time was the *same* for both.)

Try counting the number of vibrations in each path. Can the frequency (number of vibrations per second) of each tuning fork be determined by counting the vibrations traced by each needle on the smoked glass? (Not unless the movement of the smoked glass was accurately timed as one second.) Does the experiment show that the two tuning forks have different frequencies? (Yes, because in the same length of time, one traced more vibrations than the other.)

Encourage some of the students to find the frequency (number of vibrations per second) of each of the fundamental tones produced by the white keys on a piano. A seven octave piano is most often tuned to these frequencies (see Fig. 16.7).

Fig. 16.8 Comparison of range limits within which music is written for each instrument and voice.



Notice that a seven octave piano has a range of pitch from 64 to 8192 vibrations per second. The frequency of middle C has been set at 256. Students who are interested in mathematics will quickly see an orderly relationship between each note and the same note one octave higher. (The frequency of a note doubles in each higher octave.) It is important for students to begin to realize the interrelationship between music, science, and mathematics.

In searching for the piano frequencies, some pupils may discover that other musical instruments may have a frequency range different from the piano range. Some instruments can produce frequencies lower than 64 vibrations per second; other instruments, frequencies above 8192 vibrations per second. Those students who play musical instruments could ask their music teachers to help them answer these four questions (see Fig. 16.8 for answers to these questions):

1. Can my instrument produce higher pitched tones than a piano?
2. Can my instrument produce lower pitched tones than a piano?
3. What is the lowest and highest note it is possible to produce on my instrument?
4. What are the frequencies of these two notes?

12. What frequency range is used to test the ability to hear? Through what frequency range is it possible to hear sound? What are the names of frequencies that are too low and too high to be audible?

Review the frequency range of a seven octave piano. (64 to 8192 vibrations per second.) Find out if all the children can hear both the lowest and highest note the piano can produce.

Ask the school nurse to bring to your classroom the *audiometer*, with which she checks the children's ability to hear. Have her demonstrate the lowest and highest frequency it can produce. She should demonstrate both of these frequencies at the lowest and highest *intensity* the audiometer can produce. With her help, have the children discover that she controls the *intensity* or the loudness of the frequencies which the machine produces. Ask her to introduce the word *decibel* and explain that it is a term used to measure the intensity or loudness of the sound. With the audiometer, she can help the children answer questions like these:

1. Can I hear the lowest frequency at the lowest intensity?
2. Can I hear the highest intensity at the lowest frequency?
3. Can I hear the lowest intensity at the highest frequency?
4. Can I hear the highest frequency at the highest frequency?
5. What is the lowest frequency this audiometer produces? (Many produce 125 vibrations per second for the lowest frequency.)
6. What is the highest frequency this audiometer produces? (Many produce 8000 vibrations per second for the highest frequency.)
7. What is the frequency range of this machine?
8. Is the full range of the machine used in a hearing test? (Not always. The range used is determined by the health department. Many states require that tests be conducted using frequencies between 250 and 8000 vibrations per second.)
9. What is the lowest intensity this audiometer produces? (Many have a low intensity of minus 10 decibels.)
10. What is the highest intensity this audiometer produces? (Many have a high intensity of 100 decibels.)
11. What intensity do you use when you use the audiometer? (Fifteen decibels is commonly used because it matches the intensity of speech.)
12. When do you use a higher intensity? (When frequencies at an intensity of 15 decibels cannot be heard.)
13. Why is the frequency range used to test the ability to hear less than the frequency range of the piano? (The frequency range of the audiometer test is the frequency range of *speech* and is known as the *speech range*. Most people hear both lower and higher musical frequencies.)

Have your pupils use books to find the lowest and highest possible audible tone frequencies for people. (The audible tone frequency range for humans is between 20 and 20,000 vibrations per second.) However, the lowest and highest frequencies that one person can hear may not coincide with the lowest and highest another person hears. Frequencies above 20,000 produce *ultrasonic* sound ("silent" sound) which is not audible to people. Frequencies below 20 vibrations per second are called *infrasonic* sound.

13. What living things produce and hear ultrasonic sounds? How is ultrasonic sound used?

There is a whole ultrasonic range of sound that is commonly produced and heard by some insects, birds, fish, and mammals. Encourage some of the pupils to read about and report on the ultrasonic frequency produced by night-flying bats, including how bats use this high frequency to avoid flying into obstacles and to locate the flying insects on which they feed. This should erase the erroneous belief that bats fly into people's hair.

The pupils may wish to read about other animals that hear ultrasonic sound (see Table 16.5).

Invite someone in the community, who has trained his dog to respond to the ultrasonic sound of a dog whistle, to demonstrate for your class how the dog obeys this sound. Pupils will

Table 16.5
THE HIGHEST FREQUENCIES OF SOUND HEARD OR "SENSED" BY PEOPLE AND BY SOME OTHER KINDS OF ANIMALS

Kinds of Animals	Frequencies Heard or "Sensed" [frequencies listed are in vibrations per second (vps)]	
Bats	130,000	(Bats can hear frequencies from 20,000 to 130,000)
Cats	30,000	
Dogs	35,000	
Fish (Sea Robin)	2,000	(Sea robins can hear frequencies from 700 to 2,000)
Grasshoppers	100,000	
Pigeons	15,500	
Porpoises	150,000	(Porpoises can hear frequencies from 150 to 150,000)
People	20,000	(From 20 to 20,000. Most adults cannot hear frequencies higher than 17,000.)

not hear the sound of the whistle because its frequency is above 20,000. However, dogs hear it and can be trained to obey signals from it.

Most tape recorders record sound at two speeds; and a few, at three speeds. At the highest speed, record on a tape recorder the "silent" sound of a dog whistle. Rewind the tape and play the tape back at the *same speed.* Why can't the sound be heard? Rewind again and play back the tape at the recorder's *slowest speed.* Why can you now hear sound? (The slow speed of the recorder slows down the number of vibrations per second so that their frequency is within the audible range.)

At the highest speed, record on a tape recorder a very high violin note, sustained for 10 seconds. *Listen* to this recorded tone as it is played back at the same speed. Listen to it at slower playback speeds. *Watch* the different speeds at which the tape moves from one reel to the other. *Time* the playback of the recorded 10-second violin note. Why is its pitch lower at slower playback speeds? (Slower speeds reproduce the recorded vibrations more slowly. There are fewer vibrations per second. When the number of vibrations per second changes, the pitch changes. Pitch is determined by the number of vibrations per second.)

Let the children record a song and a poem at the highest speed. They should listen to, time, and watch the moving tape as sound is reproduced at each of the recorder's running speeds.

Have the students observe the different speeds at which the turntable on a record player spins. Show them the control that changes the speed, and be sure they understand what the numbers 33⅓, 45, and 78 mean. (They indicate the number of revolutions per minute—rpm's.) Obtain three old musical records; one should be a 33⅓ record; one, a 45; and one, a 78. First play each at the speed at which it was made to be run; then, at the other two speeds. Listen for changes in pitch. Ask the class to explain what causes them.

If a 33⅓ record is played on a record player that spins at 30 rpm's (a little slow) instead of 33⅓ rpm's, would a change of pitch be noticed? Would a trained musician notice? How would he know the pitch changed? (You might not. A musician would. He would hear and be annoyed by the lower pitch.) What would happen to the sound if the turntable turned at 35 rpm's?

Attach a small piece of white paper near the outer edge of the felt of the turntable on the record player. Set the control for 33⅓. Use a watch with a second hand to help you count how many times the paper revolves in 60 seconds. Is your record player running slow, fast, or exactly at 33⅓ rpm's?

Help your students to appreciate how electronic recorders with variable speeds have helped scientists to discover, record, and study ultrasonic tone frequencies. Students should realize, too, that there is a vast area of knowledge to be explored in ultrasonic sound and in the way animals use it.

Encourage other students to learn about and report to the class on some of the following ways in which man is learning to use ultrasonic sound:

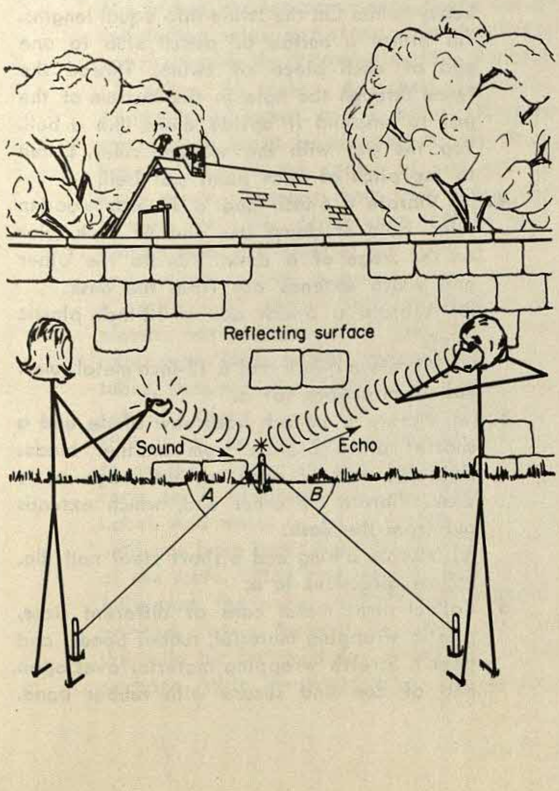
1. To clean dirty metallic objects in liquid;
2. To locate defects in metal;
3. To sterilize foods without heat quickly and thoroughly;
4. To pasteurize and homogenize milk;
5. To cook food;
6. To clear away fog and smoke;
7. To perform brain surgery without opening the skull;
8. To wash dishes and clothes;
9. To massage sore muscles;
10. To drill teeth;
11. To drill metal;
12. To cut diamonds.

14. What is echolocation? What practical use has man made of echoes? Why are scientists studying animals that use echoes?

Give the children the opportunity to discover how echoes can be used to locate the position and approximate distance of objects. Obtain either a toy frog or cricket *clicker.* These toy clickers are often sold during the Christmas and New Year holidays in toy departments and toy shops. They can often be purchased at other times of the year as well. The noisemaker on the clicker is made of a thin strip of spring steel with a dent in the middle of it. One end of the steel is clamped tightly to the toy animal; the opposite end of the strip is free to move. When the free end is pressed toward the toy animal and the pressure is quickly released, the metal strip bends and causes the dent to pop inward and outward again. The inward and outward movement of the dent produces a short, sharp click. The duration of this click varies with the size and shape of the toy animal; but, regardless of these variations, the click will not last for more than a tenth of a second. (Any sound that is one-tenth of a second or less is called a click.) These toy clickers are excellent for learning how to locate echoes (echolocation). Most other sound devices produce a vibration that is too long to be used effectively.

Have the children take the toy clicker, a ball of string, three stakes that can be used for markers, and either a tape measure or a yardstick to some location on the school grounds that is suitable for practicing echolocation. Try to find a place to stand, about 50 feet from a windowless concrete wall, where trees and shrubbery will not interfere with their experiment. (Clusters of trees and shrubbery located between the pupils and the reflecting surface—building or concrete wall—would absorb much of the sound.)

Fig. 16.9 Angle at which sound strikes wall (angle of incidence, A) equals angle at which echo is reflected (angle of reflection, B).



Choose one child to operate the toy clicker. He should stand about 35 paces or 50 feet from the reflecting surface. He should also face the wall *at an angle.* (see Fig. 16.9). As this child continuously operates the clicker, at the rate of two clicks each second, ask a second child to walk sideways away from the clicker until he finds the place where the echo of the click sounds the loudest. Mark the spot on the ground where the second pupil stood. Have several children repeat the procedure used by the second child. When the pupils agree upon the position from which the loudest echo is heard, proceed with the experiment.

Put a stake in the ground below the cupped hands of the child who is operating the clicker. Tie the loose end of a ball of string around the stake. Unroll enough string to stretch it in a straight line along this child's direct line of sight to the object that is reflecting the sound (school building or concrete wall). Push a second stake in the ground directly below this point on the reflecting surface. Tie the string around it. Place a third stake in the ground under the tip of the nose of the pupil who is standing in the position where he can hear the loudest echo. Extend string from second stake and tie it to the third stake.

Have the class compare the *angle* at which the sound *struck the reflecting surface* and the angle at which the sound *is reflected.* (The angles A and B should be equal.)

Discuss with the class the importance of this law of reflection of sound and its application in the devices used to locate missiles, planes, submarines, shorelines, and so on.

Ask the pupils how they think knowledge about (1) echoes, (2) the speed with which sound travels through materials, and (3) ultrasonic sound echoes, can be used to:

1. Measure the distance at night or through fog from a ship to an iceberg in its path;
2. Measure the distance at night or through fog from a ship to a cliff;
3. Measure the depth of the water below a surface ship or submarine;
4. Measure the distance from a surface ship to a submerged submarine or from one submerged submarine to another;
5. Determine whether there is a school of fish near a fishing boat and how far away it is;
6. Locate underground sources of water or oil.

Let them freely discuss these problems and suggest their own solutions before they are encouraged to read and report on:

1. The use of a ship's fog horn to detect and measure the distance to icebergs and cliffs.
2. The *fathometer*, which uses the echo from ultrasonic sound to measure and chart water depths.
3. The *hydrophone*, which detects two echoes—one from the ocean bottom and the other from the bedrock beneath the bottom sediments. From the difference in the time of the two echoes, the hydrophone determines the thickness of the sediments.
4. The *sonar* (sound navigation and ranging), which beams ultrasonic sound in *all directions* and, from the returning echoes, determines the direction, distance, and identity of underwater objects, such as submarines, schools of fish, whales, and underwater obstacles.
5. How geophysicists use the echoes from explosions, which they set off deep in the ground, to locate underground oil or water.

Ask other interested students to read and report to the class on what scientists have learned and hope to accomplish from a more complete knowledge of how bats and porpoises receive and use the echoes from the ultrasonic sounds they produce. Scientists know these two mammals use a form of sonar echolocation in their search for food, and hope that a study of it can lead to improvements in man-made sonar. (Bats are echolocation experts. They depend upon echoes to direct them to their prey. When a bat is on a hunting flight, it periodically emits sound vibrations and follows the path of the echoes reflected from flying insects. In one evening a bat catches enough insects to equal its own weight. Porpoises also use echolocation to hunt for food.)

Many blind people also develop a keen sense of echolocation. The children may want to discover how a blind person can tell when he is approaching and moving away from an object. Let the class take the toy ticker out on the playground and take turns learning how to detect the difference in the echoes that are reflected from various objects, such as a large tree, a parked automobile, or from each other. Then have them listen to the difference in sound when they walk very slowly toward the object. After they have developed some skill in judging the approximate distance to the object, have them try the same experiment when they are blindfolded.

15. What determines the pitch of a vibrating mass?

Divide the class into small working groups. Provide the needed materials and instructions for the following experiments. Ask each group to decide what determines the frequency at which their materials vibrate, and the pitch which results.

1. Provide two steel or two aluminum tuning forks of *different frequencies*. Vibrate both.
2. Use 1 teaspoon, 1 soup spoon, and 1 tablespoon from the *same set* of table silver, and 3 pieces of string 48 inches long. Tie a spoon in the middle of each string. Press the two ends of the string into your ears with your fingers. Lean forward to swing the spoon gently against a desk. Listen to the vibrations that come from each spoon through the string to your ears.
3. Collect a series of empty clay flowerpots graduated in size, the same number of pencil stubs or large buttons, a wooden ruler, and heavy twine. Cut the twine into equal lengths. Tie either a button or pencil stub to one end of each piece of twine. Thread the twine through the hole in the bottom of the pot to suspend it upside down like a bell. Tap the pot with the wooden ruler. Listen to the pitch of each plant pot bell.
4. (a) Vibrate a 6-inch and a 12-inch wooden ruler. Hold or clamp one end of each ruler on the edge of a desk. Vibrate the other end which extends out from the desk.
   (b) Vibrate a 6-inch and a 12-inch plastic ruler.
   (c) Vibrate a 6-inch and a 12-inch metal ruler. Follow directions for a.
5. (a) Vibrate a 12-inch hack saw blade and a shorter piece broken from another blade. Hold the end of each on the edge of a desk. Vibrate the other end, which extends out from the desk.
   (b) Vibrate a long and a short steel nail file. Follow directions in a.
6. Collect three metal cans of different sizes, plastic wrapping material, rubber bands, and pencil. Stretch wrapping material over open end of can and secure with rubber band.

Tap "drum" head with rubber end of a pencil.

7. (a) Locate a series of paper soda straws of the *same length* but of *different diameters.* Flatten one end of each soda straw with the fingers and clip the corners with a pair of scissors. Put this end in your mouth and blow through the straws. With a little practice, you can get a loud clear tone.
(b) Provide a second series of paper soda straws of the *same diameter,* but cut to *different lengths* with a pair of scissors. Follow directions given in a.
(c) Finally, show this group and the class what happens when the *teacher* rapidly cuts small sections from the end of the straw while a student blows a long steady note through the straw.

8. (a) Provide many different sizes of small-necked bottles. Blow across and into all the bottles.
(b) Provide different sizes of test tubes. Follow directions given in a.

9. Use two rubber bands of *equal length* but of *different widths,* two nails, a hammer, and a block of wood. Drive the nails into the wood so the bands will need to be stretched to be hooked around them. Place first one band and then the other around the nails and pluck the bands.

10. Obtain one length of wood about $50 \times 1\frac{1}{2} \times \frac{1}{2}$ inches, a ruler, saw, pencil, brace and bit for drilling holes, and string. Saw wood into approximately the following lengths : 8 inches, $7\frac{5}{8}$ inches, $6\frac{1}{2}$ inches, 6 inches, $5\frac{3}{8}$ inches, $4\frac{7}{8}$ inches, $4\frac{1}{2}$ inches, and 4 inches. Listen to each piece as it is dropped to the floor. Bore a hole in the center of one end of each piece. Suspend them with string tied through the holes. Strike each with the ruler.

11. Obtain eight test tubes of the same diameter and length, water, a pointed wax crayon, a package of jello, a medicine dropper, an electric hot plate, masking tape, and a test tube rack. Blow across and into all 8 test tubes. They should all produce the same pitch. Label a piece of masking tape "do" and stick it to one test tube. Add enough water to another, with a medicine dropper if necessary, so it produces the next tone, "re." Label. Add water to the remaining test tubes until you have tuned them to the eight notes of the scale. Label each of the tubes. Carefully mark the water level in each with the pointed crayon. Remove the water. Prepare the jello by following the directions on the package. With the liquid jello, refill the test tubes to the levels previously marked. Stand the tubes vertically in the test tube rack until the jello sets. Blow across and into each of the tubes.

12. Collect 8 soft drink bottles of one make. Blow and tune with water, as in number 11, until the eight notes of the scale can be produced.

13. Find a tall thin vase or pitcher. Fill with water either from a faucet or from another container. Adjust the stream of water so that it has a small, steady flow. Listen to the pitch change as the water is filling the vase or pitcher.

14. Use 8 iced tea glasses, a wooden ruler, masking tape, crayon, and water. Tap all 8 glasses with the ruler. They should all produce nearly the same pitch. Add enough water to seven of them to produce the 8 notes of a scale.

Ask each group of pupils to demonstrate their experiment and report on their findings. Help the class to conclude that, in their experiment, the mass of the vibrating object was the factor that determined its pitch.

Use the equipment from number 9. Stretch the wide rubber band around two nails. Pluck and listen to the pitch. Then remove the band from one nail, stretch it further, and twist about half of this stretched length around the nail. Hold the band secure while some child plucks it between the nails. Listen to the changed pitch. Help the pupils to see that now only part of the band is vibrating or that the vibrating mass is less. Notice too that the band is thinner. Stretching or tightening a vibrating material reduces the mass that can vibrate, and this, in turn, raises the pitch.

16. How can a musical instrument produce so many musical notes?

Divide the class into groups. Ask each group to make a study of one of the following musical instruments to determine how it can be made to produce musical tones of different pitch. Ask the music specialist to help the students with this problem. (see Fig. 16.9.)

1. marimba
2. xylophone
3. piano
4. pipe organ
5. flute
6. clarinet

7. saxophone
8. slide trombone
9. tuba
10. harp
11. violin
12. cello
13. bass viol

17. How do loud and soft sounds differ? What is intensity? What is amplitude? What is loudness? What is a decibel?

Select a fairly long paragraph from one of the students' textbooks. Ask the class to read this paragraph as *softly* as possible. Then have them reread it as *loudly* as possible. Be sure that the class realizes that each time they produced the same sounds, sound combinations, and the same number of words. Then ask, "Can you describe what you did differently to produce loudness?" The students will quickly agree that they used more energy.

Ask the class to watch and compare the motions and the sounds a drummer makes when he beats a drum gently with those he makes when he beats it harder. (He uses more energy to produce the loud sounds.)

Tap a tuning fork gently. Listen to it. What kind of sound is it making? Tap the same tuning fork with much more force. What kind of sound do you expect to hear? Touch the vibrating tuning fork. Can you feel when it is making a loud sound?

Sprinkle a fine dry material on a drumhead. Try using pepper, yellow cornmeal, iron filings, or ground cloves, etc. Beat the drum gently. Watch what happens when the drumhead vibrates. Now beat the drumhead with more force. Why do the small particles jump higher? (The vibrations of the drumhead are stronger and strike the particles with more energy.)

Tap a tuning fork lightly. Touch one of its vibrating prongs to a suspended Ping-Pong ball. Try touching the tuning fork to the Ping-Pong ball when it is producing a louder sound. When does the ball react more violently? (When the tuning fork is producing the louder tone.)

Touch the surface of a bowl of water with the prongs of a turning fork, and compare what happens when it has been made to produce a loud sound with what happens when it is producing a soft sound. When does it make stronger waves in the water? (When the sound is loud.) When does it make stronger sound waves in the air? (When the sound is loud.)

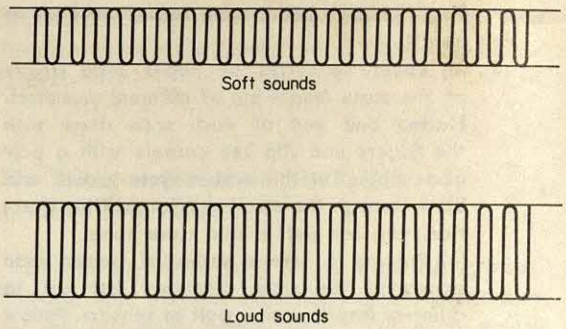


Fig. 16.10 Sound wave tracings magnified.

Follow the directions for the experience with smoked glass described in Inquiry 11. This time obtain two tuning forks that have the same frequency (produce the same tone). Cause one to produce a soft sound and the other a loud sound. How do the wave tracings of these two tuning forks differ? (see Fig. 16.10.) (When the tuning fork is tapped gently, its prongs vibrate gently and trace a wave pattern through a small distance or height. When it is tapped hard, its prongs vibrate strongly and trace a wave pattern through a greater distance or height. The strength of the vibration is called the *intensity*. Bodies vibrating with greater intensity trace higher wave patterns. The height of the wave pattern is called the *amplitude* of the wave. Therefore, the wave amplitude varies with the intensity.) How are these two wave tracings alike? (There are the same number of waves in equal distances because the frequencies—number of vibrations per second—of the two tuning forks were the same.)

Table 16.6
SOUND LEVELS IN DECIBELS

Sound from	Rating in Decibels
No sound	0
Rustle of leaves	9
Whisper	15
Quiet house	25
Home radio	45
Conversation	60
Street traffic	75
Passing train	90
Airplane engine	110
Thunder	118
Threshold of pain	120

After completing the preceding experiences, ask the pupils to try writing their own explanation for loudness. Then have them compare their description of loudness with the definition of loudness as given in science books. The students should also become familiar with the term *decibel,* which is the unit used for measuring the force with which sound waves reach the ear system. Most human ears hear sound from 1 to 120 decibels. Over 120 decibels, sounds are so loud they are painful to the human ear. The threshold of pain is at 120 decibels. (see Table 16.6 and Inquiry 9.)

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Many sounds are easily identified because they are familiar sounds.

2. All sounds are caused by something which is vibrating (rapidly moving to-and-fro).

3. An object must vibrate to cause sound. There are many ways to cause vibrations. Vibrations are rapid to-and-fro movements. Striking, blowing, rubbing or bowing, plucking, and shaking are common ways to cause vibrations.

4. There are loud and soft sounds, and high and low sounds. We enjoy the sounds of music but not the sounds we call noise.

5. Sound travels through many materials. Solids, liquids, and gases conduct sound. We hear most sounds through air. Sound travels through many materials better than it does through air. Some materials conduct sound better than others. Sound cannot travel in a vacuum. Sound must have a material (medium) through which to travel.

6. We can see a sound being made at a distance before we can hear the sound. Light travels faster than sound. Sound travels about 1100 *feet* per second through air which is at 0°C or 32°F. Light travels about 186,000 *miles* per second. Most liquids and solids transmit sound faster than air does.

7. In air, sound vibrations cause sound waves or compression waves which travel outward in all directions from the source of the sound.

8. Sounds are produced in different ways by different animals. Each sound produced may have a definite purpose.

9. Animals have different types of hearing organs. An animal's hearing organs are not always located on the head.

10. Sound can be directed by limiting and controlling the spread of sound waves in all directions. Echoes are reflected sound. Soft absorbent materials prevent the multiple echoes which can be annoying in rooms such as auditoriums. Soundproof materials absorb rather than reflect sound.

11. All sounds are caused by vibrating objects. The highness or lowness of the sound is called *pitch.* A high pitch is produced by an object that vibrates rapidly and a lower pitch is produced by an object that vibrates more slowly. The number of vibrations per second a vibrating object makes is called the *frequency* at which the object vibrates. The larger the frequency, the higher the pitch; the smaller the frequency, the lower the pitch. Pitch is determined by a sounding object's frequency of vibrations. The pitch of every musical note is identified by its frequency number. Scientists have standardized the pitch of middle C at a frequency of 256. Above and below this frequency, musicians have arranged many frequency steps called *notes.* They have arranged a sequential number of notes into an octave. The relationship between the frequencies of the notes in the scale and between octaves is a mathematical one. There is a close relationship between music, science, and mathematics.

12. Audiometers test people's ability to hear the frequencies within the speech range. In rooms that are not soundproofed, people normally hear frequencies from 250 to 8000 vibrations per second at 15 decibels of intensity. People have a possible audible range of 20 to 20,000 vibrations per second. Frequencies above 20,000 produce *ultrasonic* sound; below 20, *infrasonic* sound.

13. Ultrasonic sound is a part of our environment. Many animals hear ultrasonic sound; others produce it as well as hear it. With the help of electronic equipment, scientists are studying the world of "silent" sound. Ultrasonic sound has many uses.

14. Echolocation is the process of locating an object by an echo received from it. Some animals hunt for food in the air or water by following the path of the echo reflected from their prey. Echoes can be used to locate distant objects, to determine their distance and to identify them. Scientists, by studying the sonar used by bats, porpoises, and other animals, hope to improve man-made sonar.

15. Large bodies vibrate more slowly than small bodies of the same material. Frequency and pitch depend on the mass of the vibrating object.

16. Some instruments have different-sized and separate vibrating masses for each pitch (note) they can produce. On other musical instruments, the player can control the pitch (notes) that the instrument can produce by controlling the amount of the instrument's mass that he will cause to vibrate.

17. Sound is a form of *energy* which we hear. Energy is needed to produce a vibration. The energy from a vibrating body produces sound waves. When the sound waves strike the ear drum, the auditory ear system interprets the energy received as sound.

The more energy used to vibrate a body, the stronger the vibration that results. The more strength a vibration has, the stronger the sound waves that are produced. The more force the sound waves have, the louder the sound that is heard.

Intensity is the amount of energy with which a vibrating body produces sound waves. *Amplitude* is the term used when referring to the strength or height of a sound wave. *Loudness* is the auditory system's interpretation of the amount of energy with which sound waves reach it. A *decibel* is the unit used to measure the force with which sound waves reach the ear system.

Chapter Seventeen

Magnetism

In this chapter only a detailed "Summary of Science Findings" is included. The science finding summary *can be used by teachers* as the base for (1) making a list of sequential inquiries and (2) planning experiences for investigating the inquiries.

By rereading the chapters on Overview, Goals, and Evaluation, a teacher could develop the study of magnetism *into a strong illustration of the points these chapters make.* Plan experiences that *will force children:* (1) to make *their own discoveries;* (2) to *experiment personally* with magnets; and (3) *to use the process skills of critical and creative thinking* in order to carry out *their own scientific investigation* of this area of knowledge.

At the same time, the teacher should *make specific plans* for evaluation of each child and group. Plan this evaluation to measure progress in (1) the rediscovery of scientific knowledge; (2) the use of the process skills of critical and creative thinking; and (3) the degree to which problem solving abilities and desirable attitudes are displayed.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

Many toys contain magnets. It is better to say a magnet *attracts* than to say it picks up things. Magnets do not attract everything. *Some metals* are attracted by magnets; others are not.

Iron, steel, nickel, cobalt, chromium, and the magnetic alloys called permalloys are attracted by magnets. Metals that are attracted by magnets are referred to as *magnetic metals.*

Magnets are used in many ways. The needle in a magnetic compass is a magnet. A magnetic compass points in a north-south direction unless it is too near a magnetic or a magnetized substance. Any magnet can be used as a compass.

The places on the magnet that are strongest are called *poles.* The poles are usually located on the ends of the magnet. The poles have more attraction than the rest of the magnet. Some magnets of the same size have more attraction than other magnets. Small magnets *may have more attraction* than large magnets.

A magnet's attraction is caused by a force called *magnetism.* Because magnets attract magnetic objects without touching them, magnetism must extend beyond the magnet. Magnetism extends farther beyond the poles of some magnets than others.

Magnetism cannot be seen. Magnetism extends into the air around magnets. It also extends through nonmagnetic materials that are not too thick. Magnetism does not seem to extend through magnetic metals.

The magnetic force of a strong magnet can be felt when it is attracting a magnetic metal. The magnetic force with which two strong poles attract or repel each other also can be felt.

Two unlike magnetic poles attract each other and two like poles repel each other. A north and south pole attract each other. Two north or two south poles repel each other.

Small steel objects can be made into magnets by stroking them with a magnet. The magnetic material in the steel object becomes magnetized. The magnetized object has poles. A floating magnetized object acts as a magnetic compass.

A magnet can be ball-shaped. The earth is nearly spherical in shape. The earth is a *huge spheroidal magnet* with two magnetic poles; a north magnetic pole and a south magnetic pole. A magnet free to swing (a compass) will be attracted to another nearby magnet. The unlike poles of the two magnets will attract each other. When there is no second nearby magnet, a compass (magnet free to swing) will be moved by the magnetic poles of the magnetic earth. The swinging magnet will align itself in a north-south direction.

The *magnetic poles of the earth* are not in the same places as its geographic poles. Most authorities agree that the *earth's north magnetic pole* is located in the *southern hemisphere* and the *earth's south magnetic pole* in the *northern hemisphere.*

The magnetic force of a magnet extends into the area or space surrounding it. This area is called the *magnet's field* or *magnetic field.* The magnet's force in the magnetic field causes iron filings to line up in a pattern. The lines in the pattern are called the *lines of force* in the magnetic field. These lines of force extend from the north to the south pole of the magnet. The lines of force are concentrated at the poles. When the magnetic fields of two magnets touch, the pattern of iron filings shows that the lines of force between the magnets are attracted by unlike poles or repelled by like poles.

A magnetic field surrounds a wire when it is carrying a current of electricity. One way the magnetic field around a wire carrying a current of electricity can be strengthened is *by coiling the wire* into a smaller area. Physicists believe there are other magnetic fields of force beyond the earth.

An *iron core* is *temporarily magnetized* if it is inserted in the magnetic field that surrounds a coil of wire carrying a current of electricity. *Steel* is *permanently magnetized* if it is inserted in the magnetic field that surrounds a coil of wire carrying an electric current. Permanent magnets remain magnetized for a long time. A magnetic object becomes a temporary magnet when it is in direct contact with a magnetic field.

An *electromagnet* is made by coiling insulated copper wire around an *iron* core. The core is temporarily magnetized by the magnetic field surrounding the coil of wire in which an electric current is flowing. It is a temporary magnet because the core is a magnet *only when the current is flowing through the coil of wire*. An electromagnet can be made stronger by winding more turns of wire around the core, by increasing the size of the core, and by increasing the amount of current. The three methods can be used at the same time to increase the strength of an electromagnet.

A lodestone is a natural magnet. It was magnetized by the earth's magnetic field of force.

A magnet seems to be made of little magnets whose north poles line up in one direction and south poles in an opposite direction. These little magnets may be the atoms of magnetic metal of which the magnet is made. Not all the answers regarding the cause of the force called magnetism are known.

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Chapter Eighteen

Frictional or Static Electricity

INQUIRIES

1. What causes the small shocks people sometimes feel ?

2. How is the electricity that causes these shocks made ? What is this kind of electricity called ?

3. How do charged and uncharged objects react ?

4. What will charged objects do to other charged objects ?

5. How may frictional electricity be explained ?

6. Why are some electrically neutral materials at first attracted to, and then repelled by, charged objects ?

7. What causes the sparks, the crackling sounds, and the shocks ? What causes thunder and lightning ?

8. Why is frictional electricity also called *static electricity* ?

9. Why is frictional, or static, electricity more common in cold dry weather ? In what region of the earth is it more common ?

1. What causes the small shocks people sometimes feel?

Many children have experienced a small electrical shock when they have touched door handles, other people, and so on. Begin by letting these children tell of their experiences and then discuss with them the conditions that were present when they felt this shock. Ask them questions like these: Did you feel these shocks more frequently in the winter or in the summer? Was it a cold or a hot day? Was the sun shining or was it raining? Were you moving or sitting still when you felt the shock? What did you touch or what touched you when you felt the shock?

Some pupils will remember that the weather was cold and that the day was bright and sunny. As they recall their experiences, emphasize the fact that either they or the objects which they touched were moving. They will probably mention touching metal wall switches, door knobs, other people, pets, plastic seat covers, plastic bags, and clothing made of nylon, wool, silk, and fur. Also ask them whether they observed anything besides the feeling that they called a shock. Some children will remember seeing sparks and hearing crackling sounds.

Ask them whether they know of anything that can cause shock, sparks, and noise. They may know that electricity can do all three things and decide that what they felt, saw, and heard was caused by a kind of electricity.

2. How is the electricity that causes these shocks made? What is this kind of electricity called?

Allow the children to ponder and express their opinions about these two questions. Urge them to devise experiences which will help clarify this inquiry. Experiments such as the following can be planned and executed by children who repeatedly have been challenged to think creatively and imaginatively. Bring an old woolen rug to school. Rub and scuff shoes on the rug and then touch a metal door knob, another person, or any metal object. Touch all sorts of things. Repeat these actions in the dark at home or in some dark closet in school. While in the closet, have a girl comb her hair very briskly. Listen for crackling sounds and watch for sparks. Hold a mirror in front of the girl who is combing her hair so that she also may see if there are sparks.

This electricity was made by *rubbing* shoes on a rug and by *rubbing* hair with the teeth of the comb. Friction is caused by rubbing. The electricity made by rubbing is called *frictional electricity*. Friction builds up an *electrical charge* on some objects and these objects are *charged with electricity*.

3. How do charged and uncharged objects react?

Again provide the time and the encouragement that pupils need for personal involvement in any inquiry. While they do experiments similar to the ones here or variations of their own, watch for them to discover that *charged* objects at first *attract* and then *repel uncharged* objects. Try to make an uncharged paper towel or sheet of newspaper stay on the wall or chalkboard. (It will fall.) Now charge the paper by rubbing it with some nonmetallic object, such as a chalkboard eraser, a piece of plastic, fur, wool, or the hands. (When the paper is charged with electricity, it will be attracted to the wall and tend to stay there.)

See whether an uncharged comb attracts small pieces of tissue paper or iron filings. Charge the comb by rubbing it briskly with one of the previously named articles. When the comb is charged with electricity, it will attract the tissue paper or iron filings.

Charge a comb by rubbing it briskly through hair. Hold the comb near another child's hair. Does the comb attract this child's hair? Charge the comb again and hold it near a small stream of water from a faucet. Does it attract the water? Will an uncharged comb attract hair and water?

Rub an inflated balloon with a piece of plastic, wool, fur, or hair. Will the balloon cling to the wall? Find out whether a charged balloon will attract pieces of tissue paper and iron filings. Will it attract a small stream of water? Will an *uncharged* balloon also do these things?

Hang a pith ball on one end of a silk thread. Tie a piece of string between two chairs and suspend the pith ball from this string. (Pith is a dry material that is formed in the center of a cornstalk. Small balls of aluminum foil, or balsa wood, can be used in place of pith balls in this experiment.) Rub a hard rubber rod with fur or wool and hold the charged rod *near* the pith ball. What happens? (At first the pith ball is attracted and then it is repelled.) Repeat the experiment using a glass rod which has been charged by rubbing it on a piece of silk. (It will also attract and repel the pith ball.) What happens when uncharged rubber or glass rods are held near uncharged pith balls? (The rods do not attract the pith balls.)

Tie an *uncharged* inflated balloon to one end of a piece of silk thread. Fasten the other end of the thread to some support where the balloon can swing freely. Experiment to find out what happens when a charged rubber rod, a charged glass rod, a charged plastic rod, a charged comb, or a charged balloon is held *near* the uncharged balloon. Observe what happens. The uncharged balloon is at first attracted and then repelled by each of the charged objects. The experiences and the background given in Inquiries 4, 5, and 6 will help the children understand what is believed to cause charged objects first to attract and then to repel uncharged objects.

4. What will charged objects do to other charged objects?

Encourage the students to invent experiences that will provide evidence of how two charged objects react. The following experiences are suggestive of what pupils may do.

Inflate two balloons and suspend them as the pith ball and the balloon in the previous experiments were suspended. Rub both balloons with the same material (fur or wool). What do the balloons do? (They repel each other.)

Charge two suspended pith balls by touching each of them with a charged rubber rod. What happens to the pith balls? (They repel each other.) Charge a glass rod with silk. Hold it between the two balloons that have been charged by rubbing them with wool. Observe what happens to the balloons. Hold a charged rubber rod between the charged balloons. Observe what happens.

The children have now observed that sometimes two charged objects attract each other and at other times they repel each other. Let them discuss this phenomenon and perhaps from their observations they may tentatively decide that there are two kinds of electrical charges, that unlike charges attract each other, and that like charges repel each other. If they have studied magnetism (Chap. 17), they will recall that unlike magnetic poles attract each other and like magnetic poles repel each other. This knowledge of the law of magnets may cause them to think that something similar may be true of electrical charges.

Ask the pupils to repeat the first experiences they tried and to invent others to see whether they can verify their hypothesis—*unlike charges attract each other; like charges repel each other.* Also ask them to read books to see whether their ideas are held by authorities.

5. How may frictional electricity be explained?

Let the children try to explain what happens when an object is charged. If they have studied the molecular, atomic, and electron theories (see Chaps. 10, 11), they should remember that all things are composed of molecules, that molecules are composed of two or more atoms, and that atoms contain protons, electrons, and neutrons. Protons are believed to be positive (+) charges of electricity; electrons, negative (−) charges of electricity; neutrons, to have no charge at all. The positive charge (+) of each proton balances the negative charge (−) of each electron. An uncharged object that has the same number of protons and electrons is said to be neutral. From this scientific information concerning the electrical structure of an atom, students usually can deduct a theory which explains how charged objects differ from uncharged objects. Let the class form its own hypothesis, before checking the hypotheses of older scientists. Objects can be charged by adding or subtracting electrons.

Electrons can be rubbed off some objects more easily than others. If some electrons are rubbed off one object and cling to the surface of a second object, the object that gains electrons becomes negatively charged because it has more electrons than protons. The object that loses electrons becomes positively charged because it has fewer electrons than protons.

Rubbing hard rubber with wool or fur removes electrons from the fur or wool and adds them to the rubber rod. The *rubber rod becomes nega-*

tively charged because it has gained electrons. Rubbing a glass rod with silk causes electrons to move from the glass rod and cling to the silk. The silk becomes negatively charged and the *glass rod becomes positively charged.*

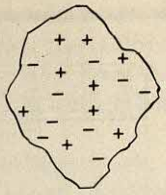


Fig. 18.1 An enlarged drawing of an electrically neutral piece of tissue paper.

6. Why are some electrically neutral materials at first attracted to, and then repelled by, charged objects?

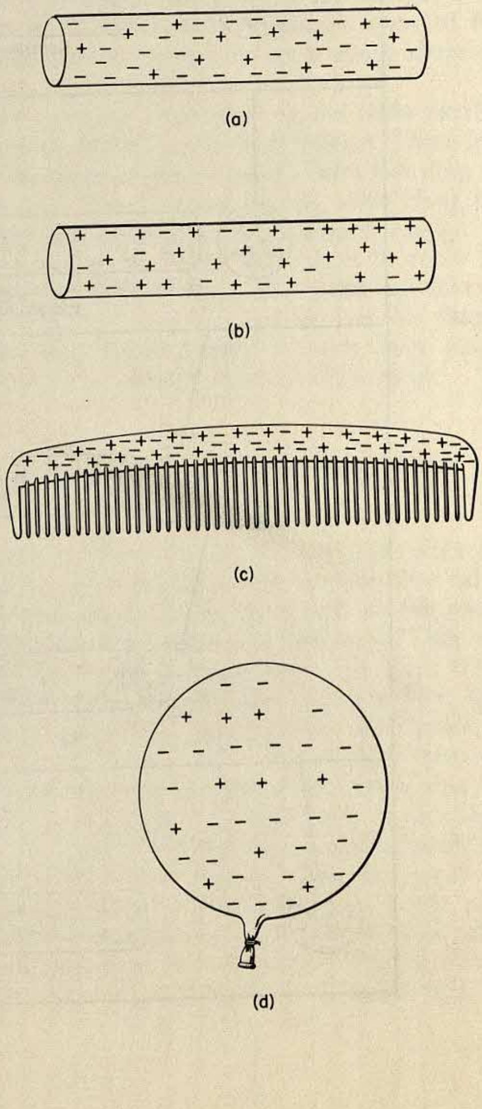
In a previous experiment, the children discovered that both negatively and positively charged objects attract pieces of tissue paper and iron filings. They may remember that the tissue paper and iron filings are electrically neutral because they contain a balanced number of electrons and protons. They may question how these electrically neutral materials can be attracted to either a positively or negatively charged object. Remind the group that positively charged objects are supposed to attract negatively charged materials, not electrically neutral ones.

Encourage the class to discuss this problem and to express ideas of how it could be explained. Have them draw on the chalkboard an enlarged diagram of one of the tiny pieces of tissue paper and put on its surface an equal number of protons (+) and electrons (−) to show that it is electrically neutral. The diagram might resemble Fig. 18.1. Now cut from colored paper, pictures of a rubber rod, a glass rod, a comb, and an inflated balloon and mark on them the signs (+) and (−) to show whether they are positively or negatively charged (see Fig. 18.2).

If the children hold the paper model of the negatively charged rubber and *near* the picture of the electrically neutral tissue paper (see Fig. 18.3) and remember that sicentists believe that (1) *electrons move readily* and (2) *like charges of electricity repel each other,* they may reason that the excess electrons on the rod repel the electrons on the paper. If this happens, the electrons may be repelled from one area of the paper to another, as shown in Fig. 18.4.

Even though the paper still has an equal number of electrons and protons, the electrons may not be evenly distributed. More of the electrons may be on the farther surface of the paper. If this happens, the *surface area of the paper nearer the rod* has more protons (+) and is *positively charged* as long as the charged rod is near it.

Fig. 18.2 (a) Negatively charged rubber rod has an excess of electrons; (b) positively charged glass rod has an excess of protons; (c) negatively charged comb has an excess of electrons; (d) negatively charged inflated balloon has an excess of electrons.



(a)

(b)

(c)

(d)

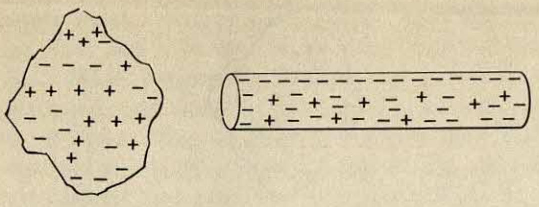


Fig. 18.3 An electrically neutral piece of tissue paper and a negatively charged rod.

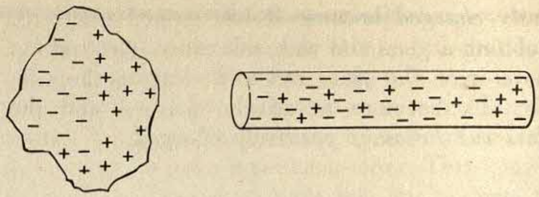
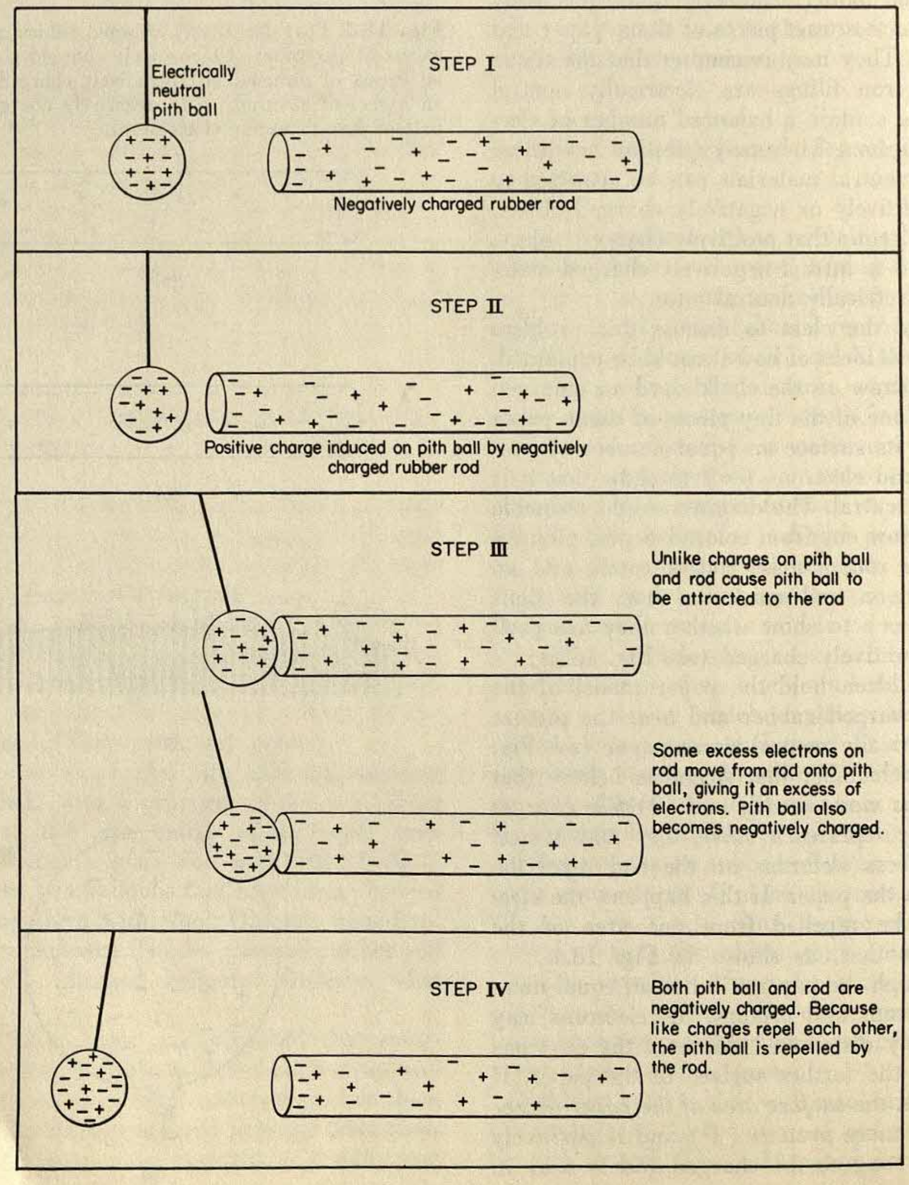


Fig. 18.4 The excess electrons on the rod will repel the electrons from one area of the paper to another.

Fig. 18.5 Why pith ball is at first attracted to, and then repelled by, a charged rubber rod.


STEP I
Electrically neutral pith ball
Negatively charged rubber rod
STEP II
Positive charge induced on pith ball by negatively charged rubber rod
STEP III
Unlike charges on pith ball and rod cause pith ball to be attracted to the rod
Some excess electrons on rod move from rod onto pith ball, giving it an excess of electrons. Pith ball also becomes negatively charged.
STEP IV
Both pith ball and rod are negatively charged. Because like charges repel each other, the pith ball is repelled by the rod.

When a negatively charged object is brought near some small electrically neutral material like tissue paper, it *induces* a positive charge on the nearer surface area of the neutral material. When the tissue paper has an *induced positive charge*, it is attracted to the negative charges on the rubber rod.

Ask the children to hold the paper model of the positively charged glass rod near the picture of the electrically neutral piece of paper. This time they should be able to reason that the excess positive charges on the rod will attract the negative electrons to the nearer surface area of the paper, thus inducing a negative charge on the nearer surface of the paper.

Ask them to use the paper models of the charged comb and inflated balloon and to decide what charge they will induce on the paper. These paper models which the children have used to help them understand what scientists mean by *induced electrical charges* can be used for a bulletin board display.

Some children may remember at this time how the pith ball was at first attracted to, and then repelled by, a charged rubber rod. Ask them to make paper models and try to figure how this may happen. Their arrangement might look like Fig. 18.5.

7. What causes the sparks, the crackling sounds, and the shocks? What causes thunder and lightning?

Have the children repeat the experiment in which they combed their hair in a dark closet. Let them watch the sparks that are produced. Have them comb their hair very slowly at first; then, have them comb faster and faster. Have them tell when they hear the crackling sounds and see the sparks.

Help the children to understand that these little sparks, together with the tiny crackling sounds, are miniature flashes of lightning and claps of thunder. They should know that when the charge is strong enough and under the proper atmospheric conditions, the electrons on the negatively charged object (the comb) will jump from it to the positively charged object (the hair). As the electrons jump through the air to the hair, they cause a spark. This spark suddenly heats and expands the air through which it passes. The expanding air sets up shock or sound waves which travel through the air to our ears. As the electrons jump from the negatively charged object, the object becomes discharged, or neutral.

Lightning is a huge spark; thunder is a very loud crackling sound. Lightning is caused by electrons jumping from the earth to a cloud, from a cloud to the earth, from one cloud to another one, or from one part to another part of the same cloud. It heats and expands the air through which it passes, causing great shock or sound waves which reach our ears. These shock or sound waves are called *thunder*.

Properly installed lightning rods protect buildings by permitting electrical charges constantly to "leak off" and thus prevent a lightning strike that otherwise might occur if the charges were allowed to accumulate. Encourage some of the children to do further research about electrical storms and lightning rods.

The jostling of gasoline in the tanks carried on trucks produces electrical charges. These fuel trucks are protected by metal chains that drag on the road. The electrical charges move along the chain and into the ground before enough of them collect inside the fuel tanks to cause an explosion. Moving cars also build up charges of electricity. Sometimes people feel this charge when the electrons jump between their hands and the car, causing them to feel a shock.

8. Why is frictional electricity also called static electricity?

The children will have discovered in their reading that frictional electricity is more often called *static electricity*. Have them look up the meaning of the word *static* in a dictionary. They will find that it means *motionless*. Let them freely discuss their ideas of why this electricity, with which they have been having experiences, is called static electricity. From their previous experiences with it, they should know that the positive and negative charges built up on objects tend to remain on the objects until a conductor carries the excess electrons from the negatively charged object or brings electrons to the positively charged object. Static electricity is called *motionless* electricity because it does not move from one charged body to a body with an opposite charge until it charges the medium (such as air) between these two charged bodies. The "charged air" acts like a conductor between the two charged bodies. The excess electrical particles move along this conductor to the oppositely charged body.

Have the children charge two suspended pith balls with a charged rubber rod. Charge the balls repeatedly by touching them again and again with the rod. When enough of the electrons have jumped onto the surface of the balls, the balls will repel each other. Record the length of time the balls remain repelled or charged. The excess electrons *tend to remain motionless* on the pith balls but eventually are conducted away by charged molecules of air. Recharge the pith balls. This time have a child touch the pith balls with his hands. The pith balls will be discharged and no longer repel each other. The excess electrons have been conducted away by the child's hands. Have the children charge the pith balls again and discharge them with other conductors.

9. Why is frictional or static electricity more common in cold dry weather? In what region of the earth is it more common?

Have the children select one simple test to detect the presence of static electricity. A comb and a few pieces of tissue paper may be the easiest materials to use. Charge the comb and observe how *many pieces of paper* it attracts. Repeat the experiment on several days, selecting days when the weather conditions are noticeably different. Control the experimentation as much as possible by always using the same comb, the same pieces of paper, and by rubbing the comb with the same number of strokes. Record the results of each test on a chart. Include in this record such data as the following: the month, day, temperature, humidity, number of pieces of paper attracted, and the duration of the charge. If the children plan to do this experiment it may be well to start the tests in the winter and make additional tests in the spring on a warm, humid day in early June. In evaluating the results of this experiment, the children should recognize that changes in humidity and temperature seem to be factors controlling the accumulation of charges.

A variation of the experiment done with the charged rod, or comb, and a tiny stream of running water from the faucet will also help the children answer the question about the effect of humidity on the prevalence of static electricity. In a first test, rub a dry rubber rod on a dry piece of fur or wool. In the second test, rub a wet rubber rod on the fur or wool. (The rod often gets wet accidentally during the first trial.) Thoroughly dry both the rod and the fur or wool and try a third time. In which test is the water attracted more? (When the rod and fur are dry.)

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Sometimes when we rub objects together, we see sparks, hear crackling sounds, and experience a feeling of shock. These effects may be caused by a kind of electricity.

2. Electricity made by rubbing two objects together is called *frictional electricity.* When some objects are rubbed together, they become charged with electricity.

3. Objects that have a charge of electricity will attract or be attracted to some objects.

4. Objects that have unlike charges of electricity attract each other. Objects that have like charges of electricity repel each other.

5. Everything is composed of atoms that contain positive and negative charges of electricity. Atoms are believed normally to have an equal number of protons and electrons. Protons are positive (+) charges of electricity. Electrons are negative (−) charges of electricity. Objects can be charged by adding or subtracting electrons. Electrons are too small to see, but we can see, feel, and hear their effects as enormous numbers of them jump from one object to another.

6. A charged body sometimes induces an opposite charge on electrically neutral materials that are near it. A charged object and a material with an induced unlike charge are attracted to each other. When the material with the induced charge touches the charged object, some of the electrons move from one object to the other. This causes the material with the induced charge to have the same kind of charge as the other object. When this happens, the like charges repel each other.

7. Under proper conditions, electrons jump from one object to another. Lightning is a huge spark produced when electrons jump from one object to another. Thunder is the result of waves produced when lightning heats and expands the air through which it passes.

8. Frictional electricity is also called *static electricity* because the electrons tend to remain on the charged object.

9. A charged object loses its charge more rapidly if the object is wet or if the air is moist. It is more difficult to charge small objects with static electricity in warm, humid weather and in warm, moist regions of the world. It is easier to do in cold, dry weather and in cold, dry regions of the world.

Chapter Nineteen

Electricity and How It Is Used

INQUIRIES

1. How is a simple electric circuit wired? Why is a switch used in the circuit?
2. What kinds of things conduct electricity?
3. Why are electric wires covered?
4. What kinds of devices contain electromagnets?
5. Why do some electrical devices "give off" light and heat?
6. How are different kinds of electric circuits wired?
7. Why should an electric circuit contain a fuse?
8. How is electricity produced and transported?

1. How is a simple electric circuit wired? Why is a switch used in the circuit?

Find out whether the children know how to wire a simple electric circuit that contains a source of electricity (1½-volt dry cell), two conductors (insulated copper wires), a 1½-volt flashlight bulb, and a lamp receptacle. Do not give them any directions for wiring this new circuit. [See Fig. 19.1(a) for a simple circuit containing one lamp.] If the children forget to

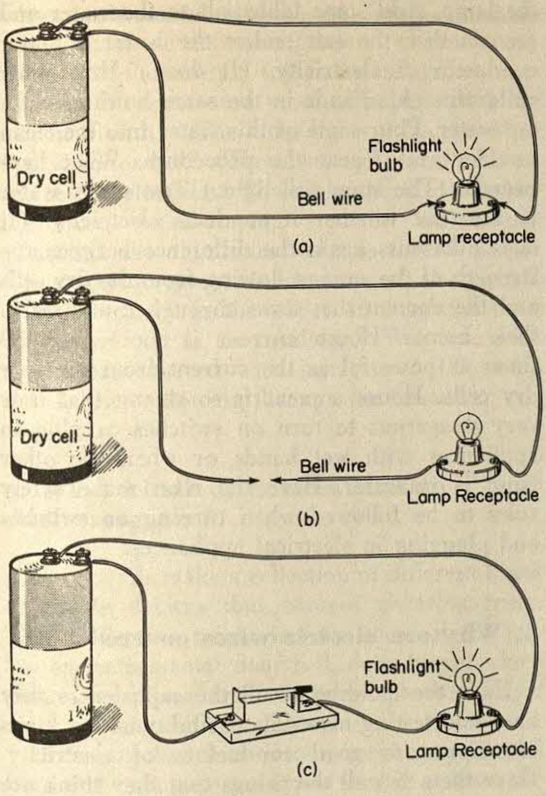


Fig. 19.1 A simple electric circuit.

remove the insulation from the ends of the wires at the dry cell and the lamp receptacle, let them discover that they must do this if the lamp is to light.

When they have successfully wired the circuit, ask them to find several different ways to *open* the circuit (make the lamp "go off"). They should discover at least three ways: 1) by disconnecting a wire from one of the posts of the dry cell, 2) by disconnecting one of the wires from the lamp receptacle, 3) by unscrewing the lamp.

There is a fourth way to *open* and *close* the circuit (make the lamp "go off" and "on"). One of the wires leading from the dry cell to the lamp can be cut into two pieces. [See Fig. 19.1(b).] By pulling the wires apart, the circuit is *opened* and the lamp "goes off"; by touching the two pieces of wire together, the circuit is *closed* and the lamp lights. Discuss how inconvenient it is to open and close the circuit by any of these four ways. Emphasize how dangerous it would be to use these four ways to turn electrical devices off and on in the children's homes and in their schools. A dry cell circuit has only a very weak current of electricity flowing through it. Develop the concept that it is safe to experiment with the electricity produced by dry cells, but it would be very dangerous to try these same experiments with the electricity flowing through the wires in their homes, at school, and in other public buildings.

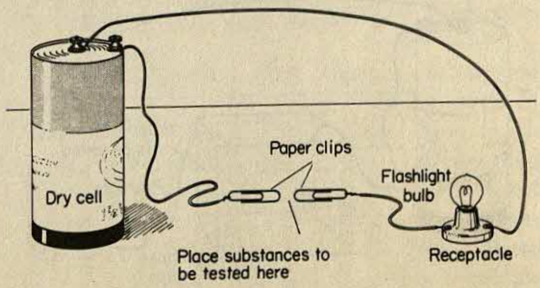
Have the children examine a knife switch like the one shown in Fig. 19.1(c). They will see the two screws to which the two ends of the cut wire should be connected. Let the class take turns opening and closing the circuit with the knife switch and watching the light "go off" and "on." Ask them to point to the part of the switch that completes the circuit and causes the lamp to light.

2. What kinds of things conduct electricity?

Substitute two paper clips for the switch used in the first experiment. Let the children discover how to open and close the circuit with this paper-clip switch. (By pushing the two ends of the paper clips together, the circuit is closed and the lamp lights. By pulling the paper clips apart, the circuit is opened and the lamp will "go off.") (See Fig. 19.2.)

Have the children collect an assortment of materials, such as small metal tools, paper, cardboard, cloth, glass, copper wire, nails, a piece of a "tin can" (tin-coated steel), paper fasteners, chalk, and so on. Place each of the materials to be tested across the space between the two metal paper clips. As the children test the different

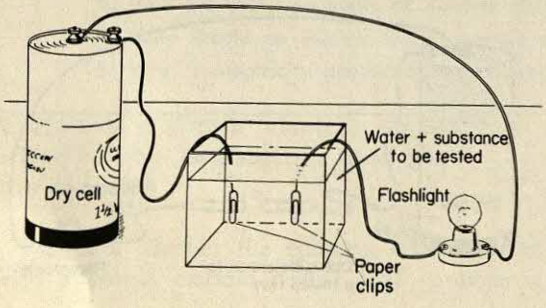
Fig. 19.2 What kinds of solids conduct electricity?



substances to find out whether they will conduct electricity, classify them into two groups: 1) things that *conduct* electricity, or close the circuit, and 2) things that do not conduct electricity. Leave all the materials used in this experiment on the table and encourage the children to test and classify them independently.

Connect four dry cells in a circuit containing the two paper clips and the lamp. (See diagram of telephone circuit in Fig. 19.8 for wiring four dry cells.) Cut several layers of blotting paper into strips about three inches long and one inch wide. Lay these layers of blotting paper across the space between the two paper clips. Why does the lamp not light? (Because blotting paper is a poor conductor of electricity.) Have the children soak the blotting paper in water and test the wet paper to see whether it is a better conductor of electricity than the dry paper. (There will be no noticeable difference.) Do not give the children the impression that current is not flowing through the circuit. Tap water does conduct electricity. The current in this circuit is too weak to light the lamp. Soak the blotting paper in a strong solution of salt water and test it. What happens? (The lamp should light. If it does not, let the children experiment to find out how close the ends of the clips must be before the lamp will light. Be sure that the paper clips *do not* touch each other.) Try another variation of this experiment. Hang the paper clips on the ends of the two wires in a glass container holding tap water. (See Fig. 19.3.) Gradually bring the clips nearer and nearer together. The class may be able to see tiny bubbles collecting on the ends of the clips, but, unless the clips touch each other, the lamp will not light. The current flowing between the two clips is too weak to light the lamp. Add some table salt to the water and see whether the salt makes the water a better conductor of electricity. (It does.) Have each child rinse his hands in the same bowl of clean tap water. Pour some of this water into the clean tumbler and repeat the procedure. What happened? (The lamp will light.) Test soapy water to find out whether it conducts electricity. (It does.) Discuss again the difference between the strength of the current flowing from the dry cells and the current that flows through the wires in their homes. House current is more than 30 times as powerful as the current from the four dry cells. House current is so strong that it is very dangerous to turn on switches or plug in appliances with wet hands or when the other hand is in water. Have the class make safety rules to be followed when turning on switches and plugging in electrical appliances.

Fig. 19.3 What makes water a conductor of electricity?



3. Why are electric wires covered?

Have the children recall the experiences they have had testing materials to find out what kinds of things are good conductors of electricity. Have them list all the things that they think are poor conductors of electricity. Introduce the word *insulators.* Insulators are poor conductors of electricity. Test these insulators in the simple circuit used in the first problem in this chapter.

Make a collection of different kinds of insulators that are used to cover electric wire and to insulate the devices used in an electric circuit. The list might be started with the insulators used in the simple circuit which they have been using for their experiments. The circuit may contain the following insulators: cotton-, plastic- or varnish-covered wire, porcelain bases on the knife switch and the lamp receptacle, plastic handle on the switch, cardboard insulator on the outside of the dry cells, fibers inside the bottom of the lamp socket, insulating compound around the edge between the center and edge of the bottom of the lamp bulb, and glass insulators holding the fine tungsten wire inside the lamp.

Wire the circuit as shown in Fig. 19.1(c). Close the circuit and feel the wires. (They may feel warm.) Remove the insulation from the wires. Lay a piece of aluminum foil under the wires. Feel the wires when the circuit is closed. Are the wires warm or hot? (They will feel hot.)

Observe the lamp. (It did not light.) What do you think made the wires get hot? (Electricity.) Remove the aluminum foil from under the wires and lay the wires on a piece of paper. Close the circuit. Result? (The lamp lights.) Do the wires feel warm or hot? (They may feel warm.) Guess where the electricity flowed in the circuit when the wires were laying on the aluminum? (Through the aluminum foil.) Is the aluminum foil a conductor or an insulator of electricity? (A conductor.) Is the paper an insulator or a conductor? (It is an insulator.) Why are wire conductors covered with insulation? (To keep the electricity flowing through the circuit.)

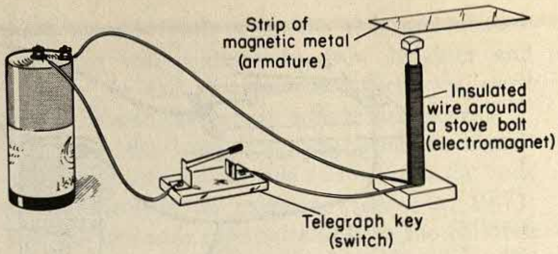
4. What kinds of devices contain electromagnets?

Help pupils make a collection of different kinds of simple devices that contain electromagnets. Their collection might include some of the following instruments: door bell, door buzzer, door chimes, telephone receiver, telegraph sounder or receiving set, and toy motors.

Organize the class into several groups and have each group find out how to wire at least one kind of an electromagnetic device. (See Figs. 19.5, 19.8, 19.9, 19.12, showing how to wire a telegraph, telephone, doorbell, and electric motor in a circuit.) Ask each group to find out how its device operates. Encourage the groups to locate information, including pictures and diagrams of the device they are studying, and have them plan to show and explain to the class what they learned. Some members of the different groups may also want to make working models of their electromagnetic devices. After each of the groups has shared its experiences with the class, make arrangements to visit a telegraph office, a telephone office, a machine shop or garage, and a junk yard where electromagnetic machinery is being used.

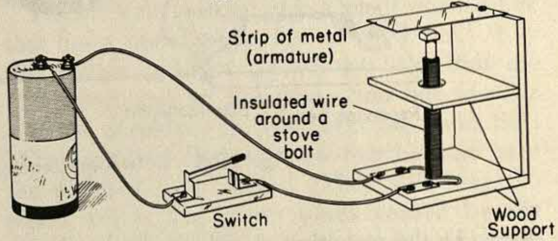
The following information will help the children build understandings about electromagnetic devices.

The Telegraph Sending and Receiving Set. The telegraph sounder contains an electromagnet and a piece of magnetic metal that is attracted by an electromagnet. The metallic arm in the telegraph sounder that is attracted by the electromagnet is called an *armature.* (See Fig. 19.4.)


Strip of magnetic metal (armature)
Insulated wire around a stove bolt (electromagnet)
Telegraph key (switch)

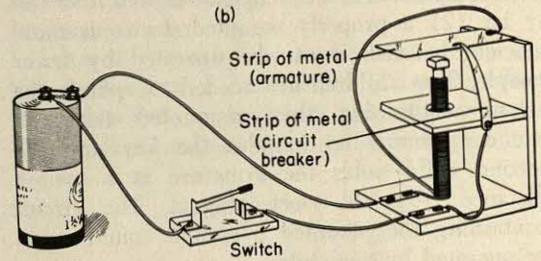
The essential parts of a telegraph circuit

(a)



A one-way telegraph and receiving set

(b)



An electric door buzzer

(c)

Fig. 19.4 Some simple electromagnetic instruments.

Figure 19.5 shows how to make a telegraph sending and receiving set and how to wire it in a circuit. Have the children look in science books for different ways to make simple telegraph sets. Fig. 19.4(a) shows the three essential parts of an unmounted telegraph sending and receiving set: (1) the switch, or key; (2) the sounder, which consists of an electromagnet and the metal arm called the *armature;* and (3) a source of electricity.

Electrical devices often appear complicated because of the mountings that hold the parts in position. Have the children notice how much more complicated than Fig. 19.4(a) the mounted telegraph sounder in Fig. 19.4(b) looks. Suggest that the group include both of these demonstrations in their presentation to the class. These two demonstrations will help the class to realize

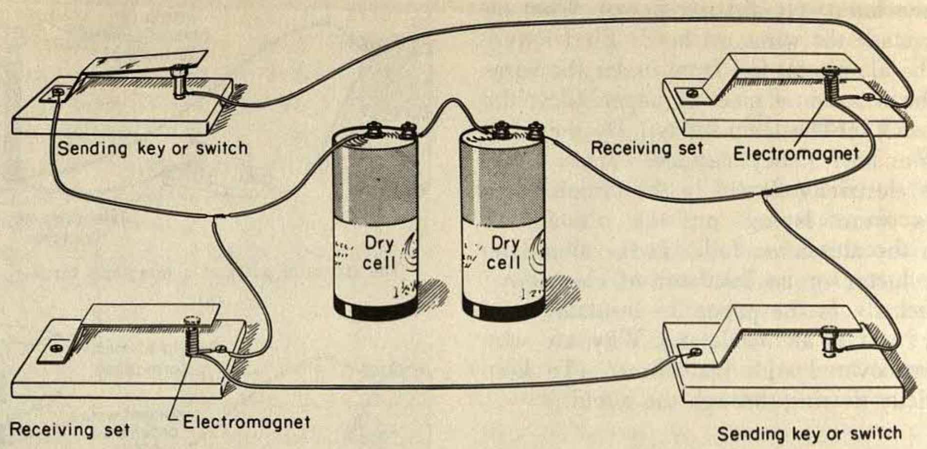


Fig. 19.5 A two-way sending and receiving telegraph circuit.

that: (1) the mounting of a device makes it appear to be much more complicated than it actually is; (2) a properly mounted device is more efficient because it can be operated by fewer people. Two children are needed to operate the circuit containing the unmounted telegraph sounder; one child handles the key and the second child holds the armature at a proper distance from the electromagnet. The circuit containing the mounted telegraph sounder can be operated by one child.

The group working on the telegraph circuit will probably want to build and wire a two-way sending and receiving set. Figure 19.5 shows how this circuit can be wired. Some members of this group might also like to prepare a report on the invention of the telegraph, the laying of the first oceanic cable, and the teletype that automatically types telegraph messages.

Have one member of the group make an enlarged copy of the simplified telegraph code and plan to show the class how to use this code to send messages. Children find it difficult to distinguish between the dots and dashes in the Morse Code. This simplified code eliminates the necessity for acquiring this skill.

To send the letter *H* which is in line 2 and column 3, the child presses the telegraph key 2 times, pauses, and then presses it 3 times. The letter *S* is 4 pause 4; and, the letter *T* is 4 pause 5. When sentences are being sent, the child learns to pause a little longer between the letters and still longer between the words.

A Simplified Telegraph Code

0	1	2	3	4	5
1	A	B	C	D	E
2	F	G	H	I	J
3	K	L	M	N	O
4	P	Q	R	S	T
5	U	V	W	X	Y
6	Z				

The Telephone Transmitter and Receiver. The telephone receiver also contains an electromagnet and a piece of metal called the diaphragm, which is attracted by the electromagnet. The telephone transmitter consists of a metal diaphragm and a small disc-shaped box filled with carbon granules. Voice waves set the diaphragm in vibration. As the diaphragm vibrates, it causes an increase and decrease in the pressure on the carbon granules. This variation in pressure causes changes in the strength and shape of the electric waves (current) flowing through the telephone circuit. The electric waves are changed back into sound or voice waves by the diaphragm in the receiver.

Help the children who are studying the telephone plan a series of sequential experiences like these:

Plan an experiment to show that carbon is a conductor of electricity. This is one way that it can be done. Remove the carbon rod from inside several "worn out" flashlight dry cells. The children need a hack saw to cut the cells. The carbon rod is attached to the center of the

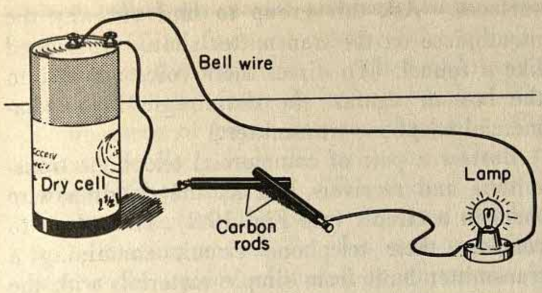


Fig. 19.6 Carbon is a conductor of electricity.

cell, so they should saw downward through the cell and halfway between the center and the outside. Wire a simple circuit in which the carbon rods are used in place of paper clips (see Fig. 19.6). This circuit can be closed by touching the ends of the rods together and it can be opened by pulling the rods apart. Have the group experiment with this circuit until they find a way to make the lamp light very dimly and then make the lamp glow more brightly. (The lamp will "give off" a very dim light if the ends of the rods touch each other. The lamp will shine much more brightly when the rods are crossed. The light will continue to grow brighter and brighter as the distance the electricity must travel through the carbon rods is decreased.)

Remove the lamp receptacle from the circuit containing the carbon rods and connect the ends of the wires to an earphone (see Fig. 19.7). Rub the two rods together and have the children listen to the scratching sound produced by the rods.

Place a wrist watch inside a small wooden box that has a cover (cigar box or chalk box). Lay the carbon rods on top of the box. Pull the rods apart and let the group find out whether with the earphones they can hear the watch tick. (They cannot.) Push the rods together and have the children listen again. (They will hear the watch tick.) The sound waves caused by the ticking watch are transmitted by electric waves to the earphone where they are changed back into sound waves again.

Unscrew the earphone and let the group examine the inside. They will see a metal disc, the diaphragm, a permanent magnet, and a U-shaped electromagnet. Open the circuit by pulling

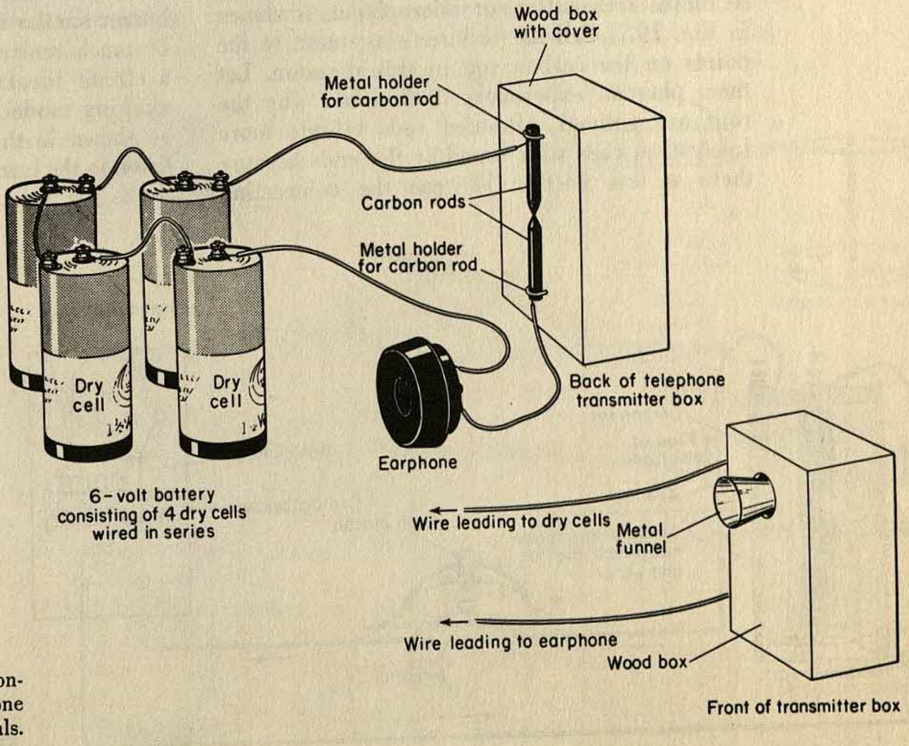

Wood box with cover
Metal holder for carbon rod
Carbon rods
Metal holder for carbon rod
Dry cell
1½V
Dry cell
1½V
Back of telephone transmitter box
Earphone
6-volt battery consisting of 4 dry cells wired in series
Wire leading to dry cells
Metal funnel
Wire leading to earphone
Wood box
Front of transmitter box

Fig. 19.7 An electric circuit containing an earphone, and a telephone transmitter made from simple materials.

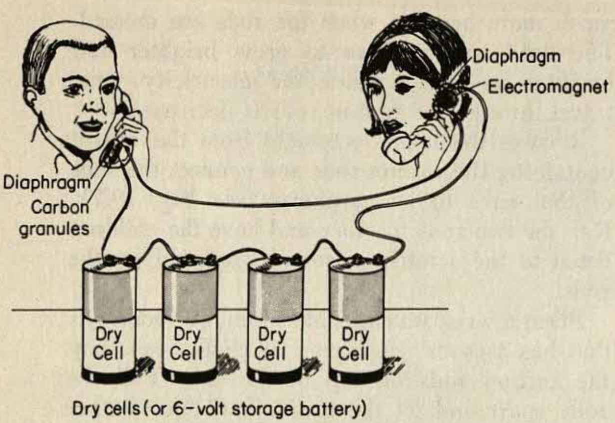


Fig. 19.8 A telephone circuit.

the carbon rods apart and have the children feel the pull of the permanent magnet on the diaphragm. The permanent magnet holds the diaphragm in position. Close the circuit by pushing the carbon rods together and have the group feel the stronger pull caused by the combined attraction of the electromagnet and the permanent magnet.

Have several of the children make a transmitter through which they can send messages. A simple transmitter, or microphone, is shown in Fig. 19.7. Call the children's attention to the points on the carbon rod in this diagram. Let them plan an experiment to find out why the rods are pointed. (Pointed rods vibrate more freely than rods with round or flat ends because there is less friction between the contracting surfaces.) Ask this group to find out why the mouthpiece on the transmitter should be shaped like a funnel. (To direct their voice waves into the box or against the diaphragm in a commercial telephone transmitter.)

Borrow a pair of commercial telephone transmitters and receivers and let the children wire them in a circuit (see Fig. 19.8). Help them to compare their telephone circuit containing a transmitter built from simple materials with the commercial sets.

This group of children might also prepare a report on the story of the invention of the first telephone and present it to the class when they share their experiences with them.

The Door Buzzer and Doorbell. A door buzzer and doorbell are very similar. They both contain an electromagnet, an armature, and a circuit breaker (automatic switch). In addition to these three parts, the doorbell has a clapper and a bell-shaped sounder. The clapper is attached to the end of the armature (see Fig. 19.9).

Locate each of the important parts of the door buzzer and bell. [See diagram of a door buzzer made from simple materials in Fig. 19.4(c).] Have the group that is studying these two electromagnetic devices plan to build a buzzer similar to the one in Fig. 19.4(c). It will be much easier for them to show the class how a circuit breaker operates if they build a large working model. Connect the buzzer in a circuit as shown in the diagram; close the switch and listen to the buzzing sound. Watch the tiny sparks fly as the armature touches the pointed piece of

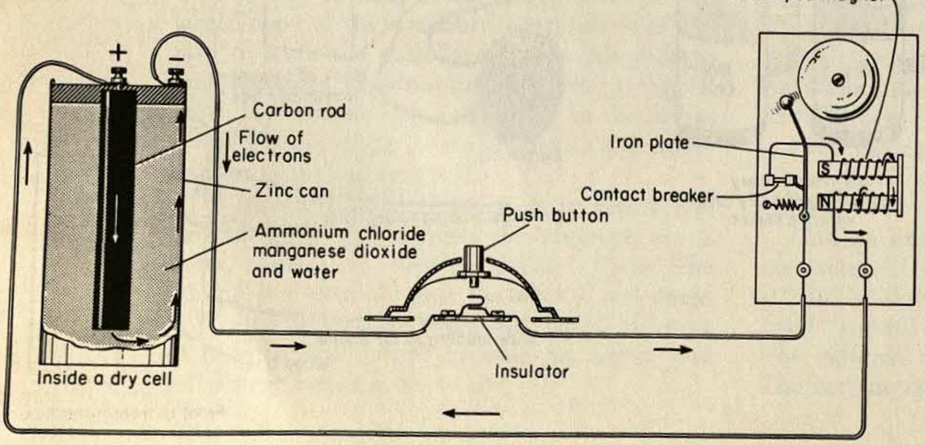


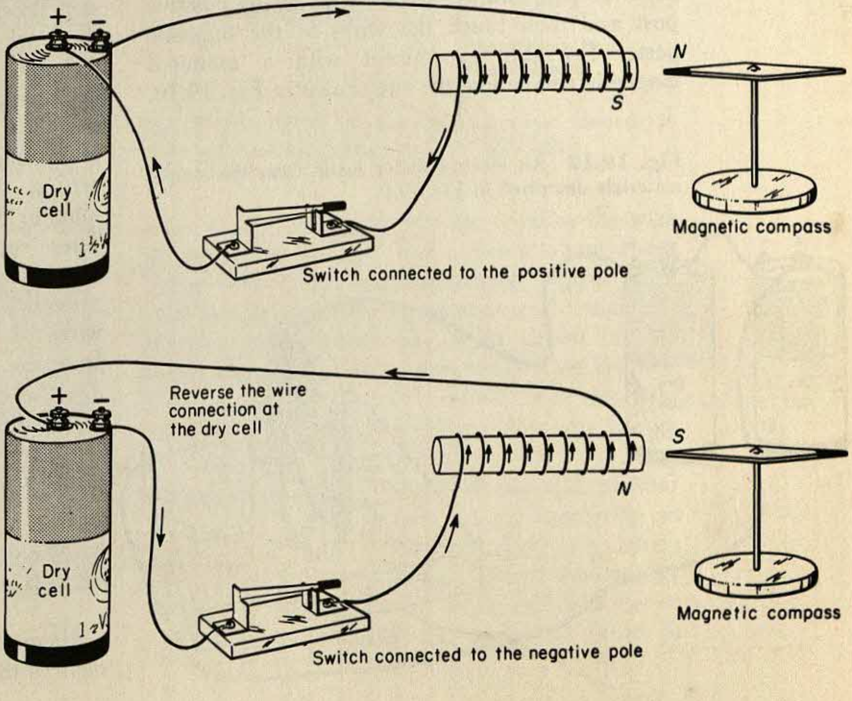
Fig. 19.9 An electric bell circuit.

metal called the *circuit breaker*. Let the group experiment to find out whether the circuit is broken as the armature is pulled by the electromagnet away from the circuit breaker. Place a thin piece of paper between the point of the circuit breaker and the armature. Close the switch. What happens? (The buzzer does not operate.) Remove the paper insulator and listen to the buzzing sound. Try this same experiment with a thin piece of metal or aluminum foil, and the buzzer will continue to buzz.

Connect a doorbell in a circuit (see Fig. 19.9) and listen to the bell ring. Find the circuit breaker and watch the sparks as the armature touches the metal contact point and moves away again. Place a piece of paper between the circuit breaker and armature of the bell and the bell will stop ringing. Pull the piece of paper out and the bell will ring again.

The Direct Current Electric Motor. Find out whether the children know what the terms direct current (*D.C.*) and alternating current (*A.C.*) mean. Direct current is produced by such devices as dry cells and storage batteries. Direct current always flows through the circuit in the same direction (from the negative post of the cell or battery to the positive, as in Fig. 19.10). Alternating current is produced by alternating current generators. Alternating current usually provides the energy needed to operate electrical devices in homes, schools, and other buildings in the community. The term *alternating current* means that the current changes its direction. The current flows through the circuit in one direction, called a *cycle*, and then it flows in the opposite direction. Most electric devices in the United States and Canada are built to operate on 60 cycles *A.C.* (alternating current). The term *60 cycles* means that the current changes its direction 60 times in a second. The motors contained in most homes and commercial appliances are alternating current motors. The diagram of a motor made from simple materials (Figs. 19.11 and 19.12) is a direct current motor.

The class has had a number of experiences with magnets and electromagnets. Find out whether they know that like poles of a magnet and electromagnet repel and the unlike poles attract. In order to keep the armature (electromagnet) in a direct current motor rotating, the poles of the armature *must be changed*. The device for changing the direction of current, called the *commutator*, is mounted on the armature. Help the group studying the direct current motor develop this concept: when the direction of the current flowing through the wires of the electromagnet is changed, the poles of the electromagnet are *reversed* (see Fig. 19.10). The



+
−
Dry cell
1½V
N
S
Magnetic compass
Switch connected to the positive pole
+
−
Reverse the wire connection at the dry cell
Dry cell
1½V
S
N
Magnetic compass
Switch connected to the negative pole

Fig. 19.10 The poles of an electromagnet can be changed by reversing the direction of the flow of current.

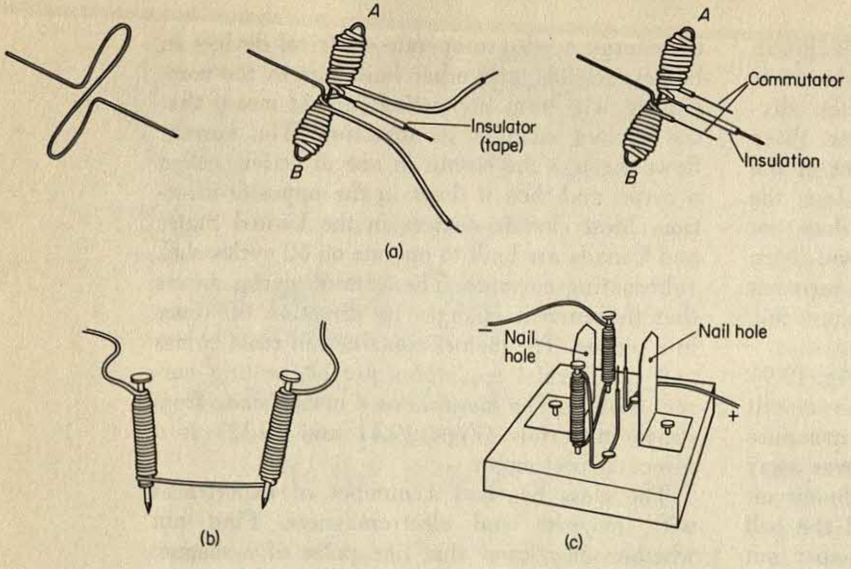
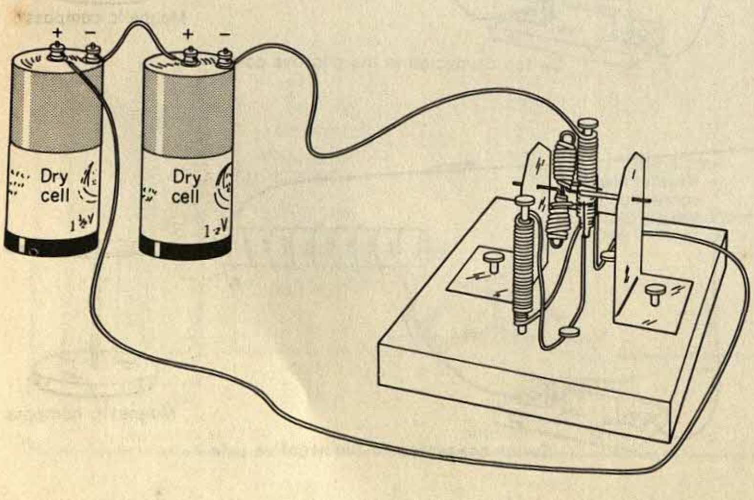


Fig. 19.11 Parts for assembling an electric motor. Part (a), armature or rotating electromagnet. Step 1: Bend paper clip. Test paper clip with a magnet to be sure it is made of a magnetic material and not of brass. Step 2: Wind armature with two layers of insulated bell wire. Wind one side clockwise and the other counterclockwise. Leave point of armature arms *A* and *B* exposed. Insulate shaft on commutator side with tape. Step 3: Remove insulation from the two commutator wires (ends of the winding), and line them up as close as possible on opposite sides of the shaft. Part (b), stationary electromagnets. Step 1: wind 40 or 50 turns of bell wire on each steel nail. Step 2: When field electromagnets are mounted in base, one will be wound clockwise and the other counterclockwise. Part (c), supports for armature shaft. Cut and bend two supports for armature shaft from tin can. Make nail holes a little lower than the top of the field electromagnets.

concept can be developed by a sequence of experiences similar to this:

Make an electromagnet and find out which is the north end and which the south. Reverse the wire connections on the posts of the dry cell and observe whether the poles have been changed. (They have.) Disconnect the wires from the posts of the dry cell. Have one child complete the circuit by touching one wire to the negative post and the second wire to the positive post and then touch the wires to the opposite posts. Try this experiment with a mounted magnetic needle like the one shown in Fig. 19.10.

Fig. 19.12 An electric motor made from the simple materials described in Fig. 19.11.



Notice what happens to the needle as the wires are changed from one post to the opposite one. (The needle whirls around.) Have the children practice reversing the current until they can make the needle whirl very rapidly. The needle is being rotated by the repulsive force exerted between the like poles of the two magnets. The needle is turning as the armature in an electric motor does. The child who is reversing the current flowing through the electromagnet is doing the work done by the commutator in the motor. Ask the children to make a large diagram of the direct current motor and use arrows to trace the flow of the current through the stationary electromagnet to the wire brushes that brush against the commutator. Notice that the commutator is composed of two bare copper wires. These copper wires are the ends of the long wire that is coiled around the armature. Each time the armature rotates, its poles are reversed as the wires of the commutator change their position from the negative to the positive brush. Encourage the children to build a motor like the one in the diagram. Some of them might also like to find directions in their science books for making different working models of electric motors.

5. Why do some electrical devices "give off" light and heat?

Have the children list some of the electrical devices they have in their homes that "give off" light and heat. This list may include some of the following: electric lamp bulbs, coffee makers, flatirons, mangles, popcorn poppers, stoves, roasters, rotisseries, sandwich grills, tea kettles, and waffle irons. Borrow several small heating appliances and a table lamp, so that the class can see the heating elements in them. The heating element in the kind of toaster in which the toast is turned by hand and in a sandwich grill can be observed without taking the appliances apart. One of the children's parents may have an old electric flatiron that the children can take apart in order to examine the heating element inside. Have the children study the heating elements very carefully. Notice that the heating element is one long piece of coiled wire or metallic ribbon. Locate the two screws to which the ends of these metal conductors are attached. Plug one of the heating devices into the alternating current circuit in the classroom and let the class observe the wire in the heating element get red-hot.

Examine the fine, tightly coiled wire in an electric light bulb. Locate the two places where the ends of this wire are attached to the side and bottom of the light bulb base. Screw the bulb in a lamp base and plug the lamp into the circuit. The filament or wire in the lamp bulb glows white-hot instantly. Have the children try to find three physical differences between the wire used in a heating device and in the lamp bulb, which cause the filament in the lamp to heat so much faster and give off white light. (First, the wire in the heating device is *larger in diameter;* second, it is much *longer;* third, the metals might be different because their colors are not the same.) Have the class check their science books to find out whether the metals in a heating device and a lamp bulb are different. (The metals are different. Nichrome—an alloy of nickel, chromium, and steel—is used in heating elements. The filament in the lamp bulb is made of tungsten.)

Have the children plan some experiments to find out whether the kind of metal, the diameter, and length of the wire affect the amount of electrical energy that is changed into heat and light energy. Their plans might include some experiments like these:

Connect different lengths of copper wire of the same diameter or thickness in a circuit similar to the one shown in Fig. 19.13.

First test a short piece of wire about two inches long. Leave the circuit closed until the wire feels hot. Record the number of seconds that the circuit was closed. Connect a piece of wire about three or four feet long in the circuit. Leave the circuit closed for the same length of time that it was closed in the first test. Which wire got hotter? (The short piece.) Repeat the test using two pieces of wire of different diameters. These two wires should be at least one foot long. (Small-diameter or thin copper wire can be obtained by pulling one of the wire strands from the twisted wire in a lamp cord. A piece of bell wire can be used for copper wire of larger diameter.) Test the thin piece of wire first and compare the results obtained with a thick copper wire. (The thin piece of wire will get hotter.) Remove one strand of wire (about three inches long) from a piece of iron picture wire. Connect it in the circuit; record the length of time it takes the wire to get red-hot. Then cut a piece about three inches long from the thin-strand copper wire used in the previous experiment and connect it in the circuit. Leave the circuit closed for the length of time it took the iron wire to get red-hot. What does this experiment show? (The iron wire changes more electrical energy into heat energy than the copper wire does.)

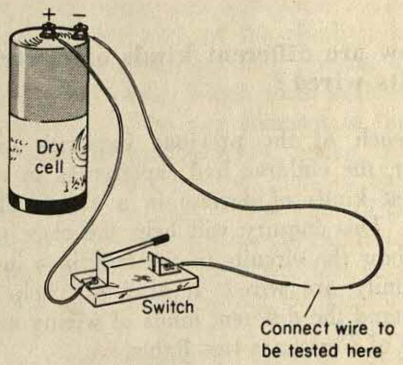


Fig. 19.13 What causes some electrical devices to "give off" heat and others to "give off" light?

Test other kinds of metals to find out whether they are as good conductors of electricity as copper. (The best conductors of electricity change less electrical energy into heat energy than poorer conductors. Copper is one of the best and one of the cheapest conductors of electricity. Silver is a much better conductor than copper, but it is much more expensive. Aluminum is also a good conductor of electricity. Both copper and aluminum are used for transporting electric power.)

Help the children summarize what they found out in their experiments with conductors of electricity. (Each of the metals used in their experiment got hot, but some got hotter than others. Even the best conductors of electricity change some electrical energy into heat energy. Poorer conductors of electricity change more electrical energy into heat energy than the best conductors. If the children visualize electricity as a flow of electrons from atom to atom through the wires, it will be easier for them to understand why no metal is a perfect electrical conductor. The atoms in the metal resist the push of the electrons against them. The electrical energy used to overcome this resistance is changed into heat energy.)

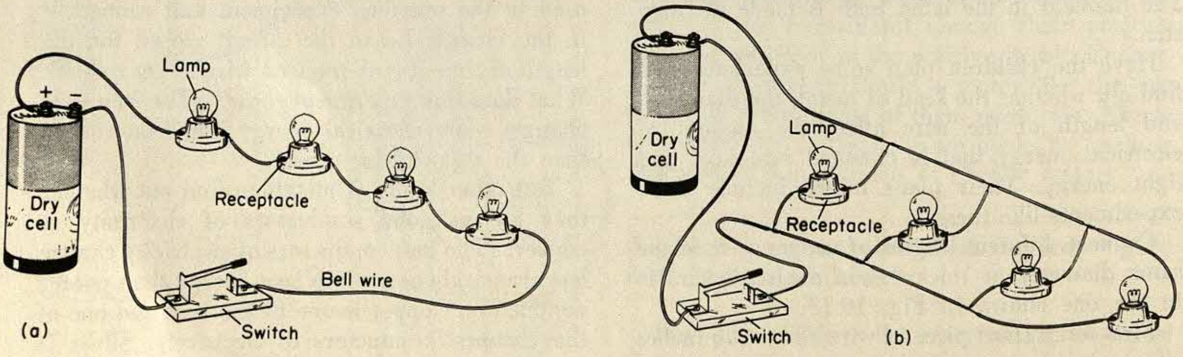
6. How are different kinds of electric circuits wired?

In each of the previous inquiries in this chapter, the children had experiences in wiring different kinds of devices in a simple electric circuit. This inquiry will help the class understand how the circuits in the buildings in their community are wired. It also will help them understand the different kinds of wiring used in strings of Christmas tree lights.

Homes and other buildings in the community are wired in *parallel*. Some kinds of Christmas tree lights are also wired in parallel, others are wired in *series*. Have a committee of children draw large diagrams on newsprint paper of the two circuits in Fig. 19.14(a) and (b), showing lamps wired in series and in parallel. Have the class examine these two diagrams very carefully. Some of the children should be able to trace the flow of electrons through these two different kinds of circuits.

In the circuit containing lamps wired in parallel, each lamp is on a subcircuit. The electricity flows into the wire attached to the negative post of the dry cell as far as the subcircuit containing the first lamp. Some of the current flows through this lamp and back into the wire attached to the positive post of the dry cell. The remainder of the current flows on through the main wire as far as the short wire leading to the second subcircuit, and some of the electricity flows through this circuit and back to the dry cell again. The same division of current occurs at the third and fourth subcircuits. Give the children an opportunity to learn how to work from a diagram. Have them wire four lamps in parallel in a circuit like that in Fig. 19.14(b). After they have finished wiring the lamps in the circuit and enjoyed seeing the lamps light, have them try to find a way to test whether each lamp is wired in a separate subcircuit. (Unscrew any one of the lamps in the different circuits and the remaining lamps will remain lighted). Turn on the lights in the classroom. How many lights are controlled by the same switch? (Usually more than one.) Plug a lamp into an electric outlet and find out whether the outlet is con-

Fig. 19.14 Electrical circuits containing lamps wired in series (a), and lamps wired in parallel (b).



trolled by any of the switches. (They usually are on a separate circuit from the switches.) Have the class try to find a way to insert a switch in the parallel circuit that they wired so that it will "turn off" only one of the lamps. Cut one of the short wires leading to a lamp and connect the switch between the two ends of this wire. Perhaps the children can think of a second method for inserting a switch in a subcircuit. (Disconnect one of the wires from the lamp receptacle. Connect another short wire to the lamp receptable. Insert the switch between the ends of these two pieces of wire.) Perhaps they can find a third method to insert a switch. (Disconnect the short end of the wire connected to one of the main wires in the circuit. Connect another short piece of wire to this main wire and insert a switch between the ends of the two wires.)

Have the children study the large diagram they drew of a circuit containing lamps connected in series. How does the current flow through this circuit? (In a circuit containing lamps wired in series, the wire filament in each lamp is a part of the main circuit. If the filament in one lamp bulb "burns out" or pulls apart, the circuit is opened and none of the lamps will light.) Let the children wire some lamps in a series circuit and find out whether the filament in each lamp bulb is part of the main circuit. (If the children loosen one lamp bulb, or remove it from the receptacle, none of the lamp bulbs will light.)

Ask the class to identify the kind of circuit in which their Christmas tree lights are connected. Borrow a string of lights that is wired in parallel and another string that is wired in series. Have the children examine the lamp receptacles and find out whether they are wired like their parallel and series circuits.

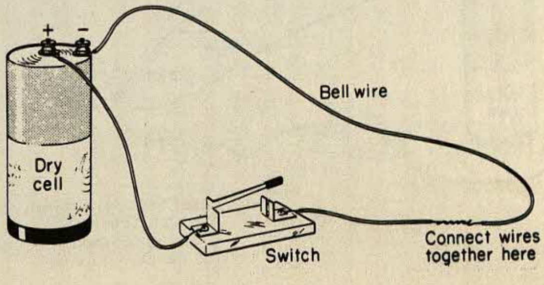
The following list of questions and answers are given as a sample of the kind of questions that could be used to test children's learnings:

1. What device is used to open and close an electric circuit? (A switch.)
2. What is the name of the cheapest of the better conductors of electricity? (Copper.)
3. What kind of metal is used in heating appliances? (Nichrome.)
4. What electrical term is used for such substances as paint, varnish, cotton, and rubber? (Insulator.)
5. Which of these instruments does not contain an electromagnet: telegraph sounder, doorbell, telephone transmitter, and an electric motor? (Telephone transmitter.)
6. How are messages carried through a telephone circuit? (By electric waves.)
7. What causes the doorbell to ring as long as the switch is closed? (A circuit breaker.)
8. In which kind of circuit do all lamps "go off," if one lamp is "burned out"? (Series.)
9. Which of these substances would not be used to transport electricity: aluminum, copper, tungsten? (Tungsten.)
10. What happens if the direction of flow of the current through an electromagnet is changed? (The poles of the electromagnet are reversed.)

7. Why should an electric circuit contain a fuse?

Have the children wire a circuit similar to Fig. 19.1 containing a switch and an electrical device (lamp bulb and receptacle). Close the circuit and have each of the children feel the wires to find out whether they are hot or cool. (They will feel cool.) Which metal in this circuit gets very hot? (The wire filament in the lamp bulb.) Remove the electrical device from the circuit and connect the two ends of the wires together. (See Fig. 19.15.) Have one of the children close the circuit and ask the children to feel the wires again. (The wires will feel very hot.) Warn the class about leaving the circuit closed for more than a few seconds at a time because there is no electrical device (resistor) in the circuit to "hold back" the current. If the circuit is closed for too long a time, the dry cell will get very hot and the liquid paste inside the seal will leak through the cell. Some of the class may have seen flashlight dry cells that got so hot

Fig. 19.15 Too much electricity will flow through a circuit that has no electrical device in it.



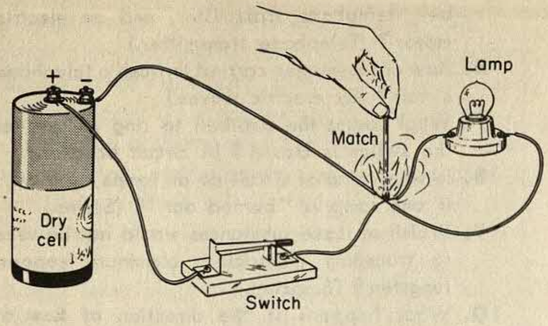


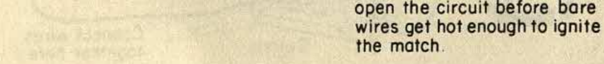
Fig. 19.16 Electric current flows through a short circuit, here caused by bare wires touching each other (the lamp will not light; the heat from the bare wires will ignite the match).

that the liquid leaked through the cells. This liquid inside of the cell must be present for the production of electricity.

Wire a circuit like the one shown in Fig. 19.1. Remove some insulation from each of the copper wires and cross them as shown in Fig. 19.16. Close the switch. What pathway is the electricity following in this circuit? (Through the bare copper wires that are touching each other.) Hold a kitchen match over the place where the wires contact each other. The wires will get hot enough to ignite the match. Observe the two pathways through which the electricity could flow. (Through the bare copper wires or through the filament in the lamp bulb.) What does this experiment show? (That electricity will not flow through a resistor if there is an easier pathway for it to follow.)

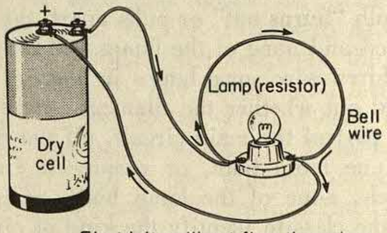
Make a fuse from a piece of foil (gum or candy bar wrappers). Connect the fuse in the circuit as shown in Fig. 19.17. (This diagram shows a circuit containing a switch, a fuse, bare copper wires touching each other, and a lamp.) What happens? (The lamp does not light, the fuse melts, falls apart, and opens the circuit.) Connect another fuse into the circuit and hold a match on the place where the bare wires contact each other. Why did the match not ignite as it did in the previous experiment? (Because the fuse melted before the wires got hot enough to ignite the match.) Why is a fuse called a *safety device?* (Because it melts, falls apart, and opens the circuit before the wires get hot enough to cause a fire.) Which metal, the foil or the copper, has a lower melting point? (The foil.) Why should a copper penny not be used as a substitute for a fuse in the electric circuit? (Because the circuit would not open when too much electricity flows through it. As a result the insulation on the wires would get hot enough to burn.)

Fig. 19.17 The fuse will "blow" or melt and fall apart when too much electricity flows through the circuit.



Fuse (lead foil) will melt and open the circuit before bare wires get hot enough to ignite the match.

Wire a circuit like the one in Fig. 19.18 showing a piece of bell wire closing the circuit around the lamp. Even though the pathway around the lamp is longer, the current flows through the best conductor (the copper bell wire). Have the children find out whether the lead foil fuse will melt if the current flows through the lamp bulb to light the lamp. (See Fig. 19.19.) (It will not.) Ask them to feel the cool wires in this circuit.



Electricity will not flow through a resistor if there is an easier way.

Fig. 19.18 A "short circuit" is not always the shortest distance.

Help the class summarize what they found out in their experiments with "short circuits." Questions similar to these might be used to guide their discussion: "What causes short circuits?" (Too much electricity flowing through the wires.) "What resists, or 'holds back,' the electricity in a circuit?" (The electrical devices or resistors.)

Why should every closed circuit contain at

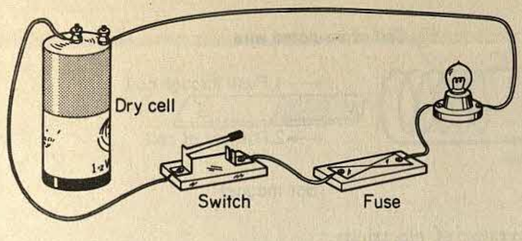


Fig. 19.19 An electrical device will "hold back" or resist the flow of electricity.

least one electrical device? (Because the electrical device resists or "holds back" the current and prevents too much electricity from flowing through the circuit.) The children may have experienced a fuse "blowing" when too many electrical devices are connected in a circuit. Perhaps the fuse "blew" during breakfast when the electric toaster, percolator, and waffle iron were connected in the same circuit. The house fuse melted and fell apart because the circuit was carrying an overload of current.

Discuss some safety precautions pupils should take in their homes to prevent short circuits and overloaded circuits. Some of the following precautions might be discussed: checking insulation on lamp cords, replacing worn lamp cords, disconnecting electrical appliances when they are not in use. The class may talk about these further safety measures: always have extra fuses available for use when a fuse "blows out." Never substitute coins for fuses in the house circuit. Never place extension cords under rugs where they may cause a fire.

Arrange with the building custodian for the children to see the fuses or circuit breakers in the circuits in the school building.

8. How is electricity produced and transported?

If the children have had the experiences suggested in Chaps. 10 and 11, they will know that all matter is believed to be composed of electrical particles. Electricity can be obtained from any substance in the world when the know-how for pushing the electrical particles called electrons has been discovered.

Encourage the children to speculate on the vast amount of electric power that would be available if man knew how to produce electricity from every object in their classroom, community, and the world. People everywhere could afford to use all the electricity they needed because it would be so cheap.

Find out what source of energy is used to operate the generators from which the community obtains its electrical power. (Large power stations usually use mechanical energy, supplied by water power or steam.) If steam is used to supply the mechanical energy, also have the children find out the kind of fuel or heat energy that is used to change the water into steam. (Either fossil fuels or nuclear energy.)

Most children associate magnetic attraction with the poles of the magnet. To understand how a generator provides the force necessary to push the current through the power lines, the children should have the experiences necessary to develop the concept that magnetic fields cause magnetic attraction. Let each child have the opportunity to feel the push exerted by the like magnetic fields of two powerful U-shaped magnets. Let each of them try to push the like poles of the magnets together and feel the force that is exerted. This force is strong enough to turn the unlike poles of the magnets toward each other.

Ask the class to find out how many tacks each of the U-shaped magnets will attract. After they have finished counting the tacks, have them try this experiment. Lay two strong U-shaped magnets on top of each other with their poles together. *If the magnets remain in this position,* which poles will touch each other? (Unlike poles.) Encourage the children to guess how many tacks two magnets will attract if they are held with their unlike poles touching each other. Try it. (They will attract only a very few tacks.) Ask two children to hold the magnets several inches apart. (Be sure that the north and south poles are directly opposite each other.) Why do the magnets attract more tacks when they are farther apart? Consider this question and plan some experiments, to check the answers given. In Chapter 17, the children used iron filings to locate the position of the lines of force in the magnetic field surrounding a magnet. If necessary, help them to recall these experiences and apply them in their experimentation. (If they use iron filings, the results of their experiments will show that when the unlike poles of the magnets are touching each other, the magnetic fields

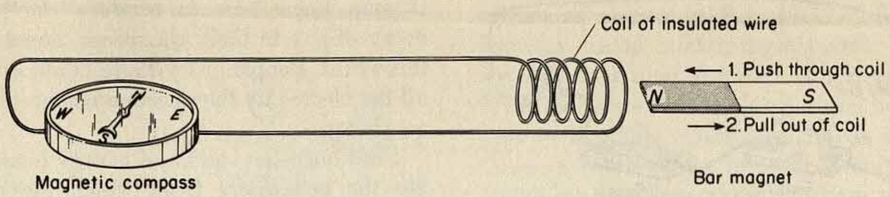


Fig. 19.20 A simple generator of electricity.

extend over a smaller area than when the magnets are farther apart.)

Collect the materials necessary to make a generator like that in Fig. 19.20. Watch the children's expression of amazement when they discover that this simple generator really *does* produce a current of electricity large enough to deflect a compass needle. Push and pull the magnet back and forth through the coil of wire. Notice whether the needle changes its direction as the magnet moves in and out of the coil. (It does.) What kind of current is produced? (Alternating.) When the magnet is pushed into the coil, the electrons are forced through the coil of wire in one direction. When the magnet is pulled back through the coil, the electrons flow in the opposite direction. Find out whether any current is produced when the magnet is held in a stationary position. (None is.) Try moving the coil of wire back and forth through the magnetic field surrounding the magnet. (A current is also produced by moving the coil.)

Borrow a hand-operated dynamo or generator from the science storeroom or the science laboratory. Have the children examine it very carefully. Notice that this generator is composed of one or more U-shaped stationary magnets and an armature that rotates through the magnetic field of these magnets. Turn the crank connected to the armature very slowly and observe the weak light emitted by the lamp. Then turn the crank faster and faster and observe the light become brighter and brighter. Compare the speed of rotation of the armature with the amount of electricity produced. (As the speed is increased, the amount of electricity produced also increases.)

If the children had the experiences suggested in Inquiry 6, Chap. 18 on frictional or static electricity, they know that an electrical charge can be induced on an object by placing it near a charged object. Ask some of the children in the class to look up the meaning of the word *induction* in an unabridged dictionary. (The definition given will be similar to this: "Induction is the action of inducing or forcing an electrical charge or current in an object by its nearness to a charged or magnetized body.") Relate the meaning of this definition to what happens when a magnet is moved through a coil of wire, or a coil of wire is moved through the magnetic field surrounding a magnet. (A current of electricity is *induced* when the magnet is moved through the conductor or the conductor is moved through the magnetic field.)

Appoint a committee of children to make a large diagram showing how electricity is transported from the electric power lines to their homes (see Fig. 19.21). Encourage the children to find out as much as they can about the devices in the diagram that are unfamiliar to them.

Some of the children may have had experiences with the transformers used with toy electric trains. Ask them why these toy trains use transformers. (These transformers step down the 110-volt house current to six volts.) Encourage the children to guess what a step-up transformer does. (It steps up the voltage.)

The concepts the children formed as a result of their experiences in Inquiries 5 and 7 of this chapter should also help them answer the questions: What happens to electric wires when a very large current of electricity flows through them? (They get very hot.) What causes this heat? (The atoms in the wire resist the flow of the electrons and some of the electrical energy is changed into heat.) Why is it more economical to transport a small amount of current than a large amount? (First, a small current causes less resistance; second, less electrical energy is changed into heat energy as the current travels through the power lines; third, smaller wires can be used for transporting small currents.)

Since transformers can only be used in alternating current circuits, the children should not

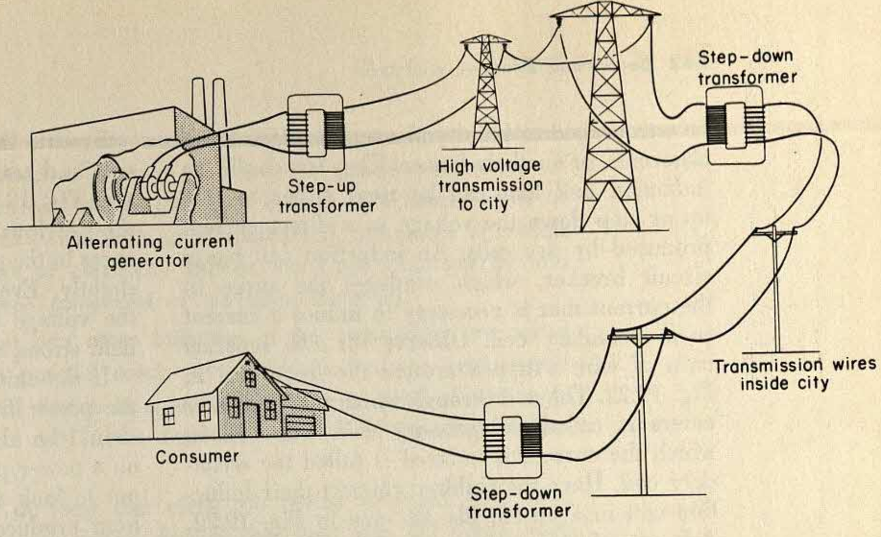


Fig. 19.21 Distribution of electricity from house to consumer. *From Jacobson, King, and Killie, Adventures in Science* (1959), *courtesy American Book Company.*

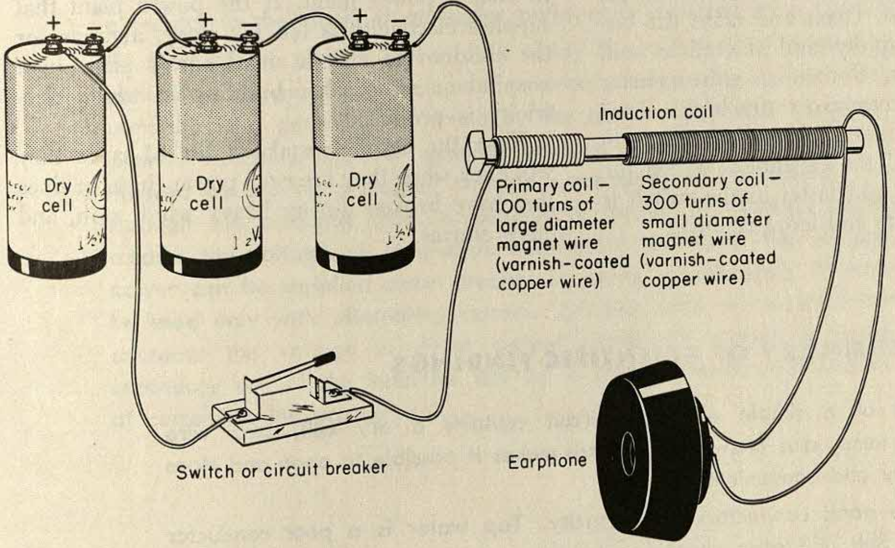


Fig. 19.22 Stepping up the voltage in direct current circuit with an induction coil.

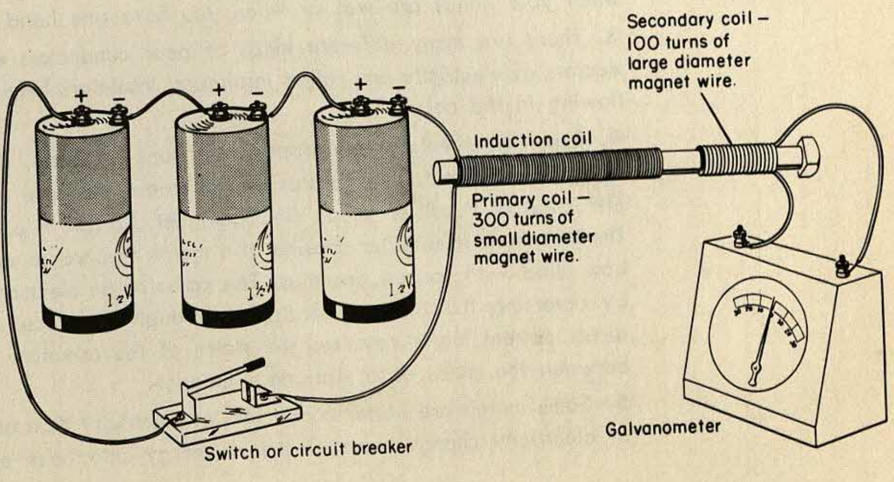


Fig. 19.23 Stepping down the voltage in a direct current circuit with an induction coil,

be encouraged to build and operate one in their classroom or in their homes. They can build an *induction coil* that can be used either to step up or step down the voltage in a direct current produced by dry cells. An induction coil has a circuit breaker, which produces the surge in the current that is necessary to induce a current in a secondary coil. Observe the two separate coils of wire wrapped around the large nail in Fig. 19.22. The coil through which the electricity enters is called the *primary coil.* The coil in which the current is induced is called the *secondary coil.* Have the children connect their induction coil in a circuit like the one in Fig. 19.22. Ask one of them to open and close the circuit breaker (switch) very slowly and listen to the clicks in the earphone. Open and close the circuit breaker very rapidly and the clicks will become much louder. Borrow a galvanometer from the science storeroom or the high school science laboratory. Connect the galvanometer in the circuit in place of the earphone. Watch the needle fluctuate faster and faster as the switch is opened and closed more and more rapidly.

Rewire the circuit containing the induction coil and use the coil to step down the voltage (see Fig. 19.23). Repeat the experiments done in the previous experience and compare the differences in the results. (The needle may vibrate very slightly. Even though the current is increased, the voltage is too low to produce a magnetic field strong enough to swing the needle.)

If the children live in a community in which the power lines are strung above ground, they should be able to find a step-down transformer on a power pole near their school. Take the class out to look at the transformer and listen to the hum produced by the resistance caused by the electricity as it flows through the coils. Plan to visit a power plant. If the power plant that supplies electricity is too far away, arrange for the children to visit a small power plant in a hospital or some other building in which electricity is produced.

Have the children make a list of rules they will obey when they are near power lines, or lines that have broken during heavy wind, rain, and snow storms.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. One type of a simple electrical circuit contains a dry cell, two wire conductors, a lamp, and a switch. A switch makes it possible to open and close a circuit safely and conveniently.

2. Metals are good conductors of electricity. Tap water is a poor conductor of electricity. Salt and soap change water from a poor conductor of electricity to a good conductor. Never turn on switches or plug in electrical appliances when your hands are wet or when you have one hand in water.

3. There are many different kinds of poor conductors of electricity. Poor conductors of electricity are called *insulators.* Insulators help to keep the electricity flowing in the circuit.

4. Such instruments as telegraphs, telephone receivers, door buzzers, and direct current motors contain armatures or diaphragms that are moved by the magnetic attraction or repulsion of an electromagnet. Carbon is a conductor of electricity. The telephone transmitter consists of a metal diaphragm and a small disc-shaped box filled with carbon granules. The poles of an electromagnet can be changed by reversing the flow of electricity through the circuit. The commutator in a direct current motor reverses the poles of the armature and causes it to rotate between the poles of a stationary magnet.

5. Some metals are better conductors of electricity than others. Poorer conductors of electricity change more electrical energy into heat energy than good conductors. Poorer conductors of electricity are used in heating and light devices. Short pieces of wire composed of metals that are not good conductors of electricity change more electrical energy into heat energy than longer wires of the same materials. Thin wires (wires with small diameters) composed of metals that are not good conductors of electricity change more electrical energy into heat energy than thicker wires composed of the same materials.

6. Electrical circuits in homes and other buildings in the community are wired in parallel. Circuits wired in parallel consist of subcircuits that are independent of each other. Each electrical device in a series circuit is a part of the main circuit; if one device "burns out," or is disconnected, none of the other devices will operate.

7. A circuit should contain at least one electrical device to resist, or "hold back," the electricity. Fuses are safety devices that melt and fall apart when too much electricity flows through the circuit. Electricity will not flow through a resistor in the circuit if an easier pathway is provided by a good conductor.

8. Most of the electric power used today is produced by alternating current generators. A generator changes mechanical energy into electrical energy. The armature in a generator is turned by the mechanical energy supplied by water power, steam turbines, or gasoline engines. A current of electricity can be induced by moving a magnet through a conductor or by moving the conductor through the magnetic field surrounding a magnet. A step-up transformer increases the voltage. A step-down transformer decreases the voltage. Electric power can be supplied more cheaply by using transformers. Transformers can be used only with alternating current. Induction coils are used to increase and decrease the voltage in direct current circuits. A current is induced in the secondary coil of the induction coil by a circuit breaker that causes a surge of current in the primary coil.

Chapter Twenty

Gravity

INQUIRIES

1. Where is "up" and where is "down"?
2. Where do things fall? Why do things fall?
3. Will gravity pull heavy objects back to earth faster than it will pull lighter objects?
4. How does man use gravity? What do we mean by weight?
5. Why do we believe our weight would be different on different heavenly bodies?
6. Why is the word "mass" used instead of "size"?
7. What causes ocean tides? What causes the planets to stay in their orbits? What causes the moon and man-made satellites to stay in their orbits?
8. How far does the earth's gravitational attraction extend beyond the surface of the earth?
9. What conditions are necessary for objects to escape the earth's gravitational attraction, or to force objects far out into the earth's gravitational field?
10. What is meant by 7 G, 8 G, or even by 0 G? Why does a rocket, at take-off, produce an effect of 7 to 14 G's?
11. What relationship, if any, exists between magnetic fields, electric fields, and gravitational fields?

1. Where is "up" and where is "down"?

Ask the children to describe what the words *up* and *down* mean to them. They will probably say that *up* and *down* are in different directions. In order to clarify their conception of *up* and *down,* have the children do this experiment. Let some of them draw small pictures showing a child with one arm upraised all ready to throw a ball into the air. Have the rest of the class draw small pictures of a child dropping seeds in a garden. The hand holding the seeds should be held down by the child's side. Then have the children cut out their pictures of these two children and fasten them on various parts of an earth globe. Be sure that at least one paper doll is located at the North Pole and another at the South Pole. Call the children's attention to the fact that all their paper dolls have their feet on the ground and their heads in the air. They will be able to see that *up* is away from the center of the earth and that *down* is toward the center of the earth.

Discuss why astronauts who televise pictures from space have difficulty determining what direction is "up" and what direction is "down." (Have the children remove the globe from their model and imagine where "up" and "down" would be for the paper dolls.)

2. Where do things fall? Why do things fall?

Have the children drop different sizes, shapes, weights, and kinds of things. Let them try dropping these things from stepladders and out of second-floor windows. Let them throw balls of different sizes into the air. Ask them where these things fall. Ask them what they think makes these things fall. (Even very young children will say *gravity* makes them fall *down.*)

3. Will gravity pull heavy objects back to the earth faster than it will pull lighter objects?

Have the children guess what they think will happen if they drop a heavy and a light object at the same time. Ask them to tell why they think it will happen. Let them plan an experiment to find the answer. Have them drop two similar objects of different weights from a second-story window or from the top of a stepladder. Arrange these objects so that they can be pushed off the windowsill at exactly the same moment. Repeat the experiment several times. After they have finished the experiment, either tell them, or have them read, the story of Galileo and the experiment he did in the Leaning Tower of Pisa. Emphasize how long ago Galileo lived and that he was the first known person to do an experiment similar to the one they did. He did this experiment before he was 28 years old. Shortly after he did this experiment, he was discharged from the university in which he was teaching. He lost his position because his ideas were too "new." People saw what happened in Galileo's experiment, but they thought that he was trying to "trick" them into believing something contrary to what they had been taught. People at that time believed that heavy things would fall to the earth faster than lighter things. Galileo was among the earliest scientists to use the problem-solving method and experimentation to find answers to questions.

It is important to emphasize that some scientists made discoveries, for which they are famous, when they were young. Children need to know that some of the world's most valuable discoveries and inventions have been made by young men and women in their twenties and early thirties. Information like this will help them to understand what scientists are really like.

4. How does man use gravity? What do we mean by weight?

Have the children discuss how people depend upon gravity to keep objects where they are placed. Help them to understand that, when an object is placed on the scales, the gravitational force pulling it down causes the scales to record the weight of the object. Children like to imagine what would happen if the earth had no gravity, or if it had more gravity. This discussion will lead directly to the next inquiry.

5. Why do we believe our weight would be different on different heavenly bodies?

This idea of different weights may be familiar to children. Some of them may have been to museums where there are rows of scales on which children can weigh themselves. Each scale is adjusted to read their weight as if they were weighing themselves on the moon, other planets, and on some of the stars.

Help them find science books that give the weight of a 100-pound earth man if he were on the sun, moon, or one of the planets. Have them find out what their own weights would be on different heavenly bodies. Perhaps they might enjoy making a chart showing the weight differences.

6. Why is the word "mass" used instead of the word "size"?

Children need to understand the correct meanings of the terms *size* (volume), *weight, mass,* and *density.* Avoiding these terms only confuses them. The following experiments will clarify these terms.

Have the class bring a loaf of unsliced bread to school. Cut a 2-inch square out of a piece of paper. Use this square as a pattern for helping them cut a 2-inch cube out of the bread. Remove the crust from the remainder of the loaf and compress the soft part of the bread into a ball. Lay the paper pattern of a square on this ball of bread and cut it into a cube the same size as the first one. Have them guess which cube of bread weighs more and ask them to give reasons for their answer. Weigh the two cubes of bread on a scale. The cubes of bread are the same *size* (*volume*) but the tightly packed one *weighs* more. It has more mass (a larger amount of matter is in it). The tightly packed cube is also more *dense* because a larger amount of matter is concentrated in it. It has more *density,* more *mass,* and more *weight,* but the same *size* or *volume.*

Children will enjoy explaining the same terms by doing a similar experiment with brown sugar. Obtain a box of brown sugar, a flour sifter, and two identical cups. Sift all the sugar onto a clean paper so that the sugar is light and fluffy. Fill one cup by sifting the sugar directly into it. With a spoon, pack into the second cup as much sugar as possible. Ask the class which cup of sugar they think weighs more, which has more mass, and which has more density.

Divide the children into small groups. Give each group one large and one small piece of paper, a rock, some Scotch tape, and two new tapered sticks of soft chalk. Ask them to roll one piece of chalk in the smaller piece of paper and to put some Scotch tape on the roll so it will stay rolled. Twist the paper together at the small end of the chalk. With a pencil, mark on the tube where the big end of the chalk comes. Untwist the end and push the chalk out of the tube. Retwist the paper. Help the children to see that the paper roll, from the twist to the pencil mark, represents the same *size* (volume) as the chalk. Now ask the children to lay one piece of chalk on the larger paper and to grind it to a powder with the rock. They should be careful to save all the powdered chalk.

Ask them to compare the mass (quantity) of the powdered chalk and the mass of the second stick of chalk. Why do they have the same mass? (It is because they have the same amount of matter in them.) Why do they have the same weight? (It is also because they have the same amount of matter in them.)

Now fill the paper tube, *to the pencil mark,* with powdered chalk. There will be powdered chalk left over. Be sure the children see that the volume of the powdered chalk in the paper tube is the same as the volume of the uncrushed stick of chalk. Then ask the children to make these comparisons: Which weighs less? Which has less mass? Which has less density? (The roll of powdered chalk weighs less; has less mass and density.)

Finally, have the children put all the powdered chalk into the tube. Ask them why they think the powdered chalk needs more space than it did before it was powdered. (Because it is less dense.) Why do the tube and the stick weigh the same? Why do they have the same mass? (Because they have the same amount of matter.)

This experiment might also be helpful. Measure the amount of cold water that it takes to fill a teakettle. When the teakettle is full, heat it until the water runs out of the spout. Measure the amount of water in the teakettle again. The water will fill the same number of containers even though some of the water spilled out when it was heated. The hot water is said to be *less dense* than the cold water because the molecules in the hot water are farther apart. In a given space, or volume, there are fewer molecules in hot water than in cold water. *Density* means the amount of matter (number of molecules) in a certain volume or space.

Help the children to understand that a larger body than the earth may have a smaller mass than the earth if its density is extremely low. Comets, together with their tails, may be several million miles long. Their density is so low, however, that the earth could pass right through a comet with no damage. Help them to understand also that a larger body than the earth, with a lower density, *can have a larger mass* than the earth if its *volume is extremely large*. The sun has a lower density than the earth, but its great size makes its total mass greater than the earth's. The moon has a smaller volume than the earth and its density is also less, so its mass and gravitational attraction are much less than the earth's.

Have the children find the densities and diameters of some of the heavenly bodies in our solar system. They can find these figures in science books. Have them find out whether each of those bodies has more or less mass than the earth and whether it has more or less gravitational attraction.

7. What causes ocean tides? What causes the planets to stay in their orbits? What causes the moon and man-made satellites to stay in their orbits?

Ask the children to state some reasons why scientists say that the moon's gravitational attraction affects the earth. If they live on the coast, they may know that the moon and sun control ocean tides. If they do not know about this relationship between the sun, moon, and our earth, have them read about ocean tides before doing the experiment described in the next few paragraphs.

Arrange a large ball, a small globe, and a smaller ball, in the size order named, to represent the sun, earth, and moon. Tie pieces of string on two opposite sides of a large rubber band. Place this band around the middle of the globe. Tie one of the strings to the ball representing the moon and the other to the sun ball (see Fig. 20.1). Discuss these models with the children. Make certain that they understand that the strings represent the gravitational attraction of the sun and the moon and that the rubber band represents the ocean waters on the earth.

Have someone rotate the globe so that the moon is shining directly on the Atlantic Ocean. Have one child pull the moon gently away from the earth while a second child holds the sun firmly in place. The rubber band, representing the oceans, is pulled away from the earth in two bulges. Be sure the children see these *two raised bulges* and understand that, on the real earth, the bulges raised by the moon's gravity would be bulges of water. Help them to understand that the extra water needed to raise these "high" bulges must be drawn from other parts of the world and that the water is lowered in the places from which the water is drawn away. The high tide *bulges* in the middle of a real ocean will cause a rise of several feet in the water level. Help the children to understand that the two places where the rubber band is tight to the earth represent the places where the water is lowered. Explain to them that the bulges are called *high tides*. Also explain to them that the *low tides* occur where there are no bulges because the water is being *lowered*. Before the children continue, be sure that they can really see the two high and two low tides in this experiment.

Compare the two high tides. Which one is higher? (The one on the side toward the moon.) If the children repeat the experiment, they can see that the moon's gravitational attraction on the water on the near side of the earth pulls the

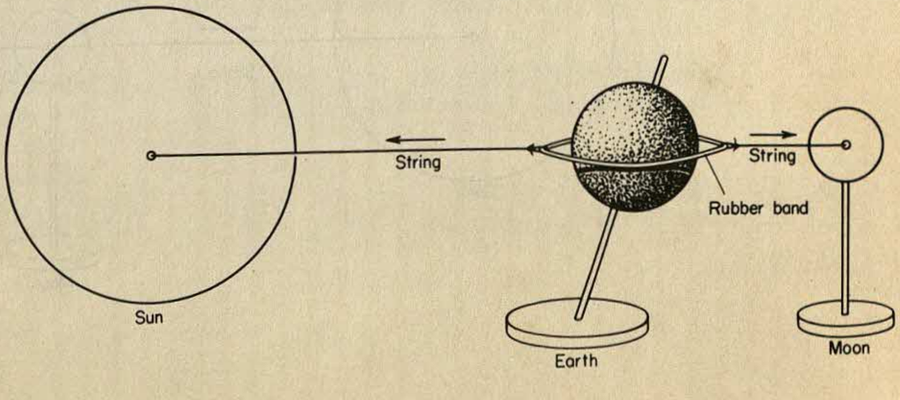


Fig. 20.1 Model illustrating the tidal bulges caused when sun's and moon's gravitational attraction is exerted on opposite sides of the earth (spring-tide).

less dense water away from the more dense, solid part of the earth. If the experiment is done on a smooth table top, they can also see the globe move a little toward the moon and away from the rubber band on the far side of the globe. This slight movement of the solid earth away from the water on the far side of the earth reduces the earth's gravitational attraction enough also to cause a high tide on the far side.

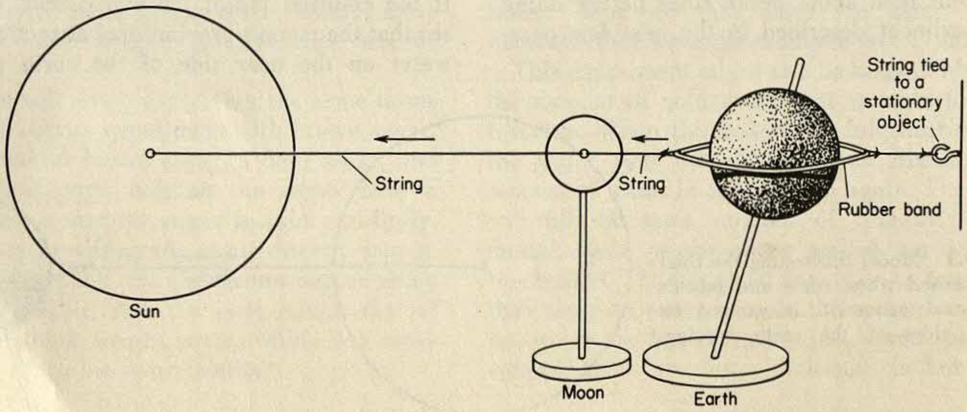
The sun also causes tides, but because of its great distance, its effect on the oceans of the world is less than the moon's effect. Now, have one child pull the sun gently away from the earth while a second child holds the moon firmly in place. The children should be able to see that the *sun* is also causing two high and two low tides. Have them locate the sides of the world that have the high tides and observe whether the globe moves slightly toward the sun. Can they explain why one high tide is higher than the other? In these experiments, why is the lower tide always on the side farther away from the heavenly body that is causing the tides?

Experiment to find out what happens to the high-tide bulges on the globe if the sun and moon pull together. First, demonstrate the high tides caused by the moon and observe the size of these high tides. Then demonstrate the high tides caused by the combined gravitational attraction of the sun and the moon. Have the children observe that when the sun and moon are in line, they both are working to raise bulges of water in the same places on the earth. When the sun and moon are in line they cause much higher tides. Tides caused by the combined pull of the sun and moon on the earth are called *spring tides*. See Figs. 20.1 and 20.2.

The children may want to watch the tidal bulges as they rotate the globe. To do this, hold the strings attached to the rubber band taut so that the tidal bulges are maintained while the globe is turned inside the rubber band. Be sure to have the children rotate the globe from west to east. They should rotate it slowly so they can watch what happens. Help the children to see why coast lines have two high and two low tides during each rotation (24 hours). Have them figure about how many hours there are between high tide and low tide, between one high tide and the next high tide, and between low tide and high tide. They may also want to follow one ocean for one complete rotation of the globe to see how many times the water rises and lowers. Have them watch one high tide (the one on the side of the globe toward the moon). See how this tidal bulge remains on the side nearer the moon and how, as the globe rotates, *different land masses and oceans* change their positions with respect to the sun and moon. When the Caribbean rotates to the place where the moon shines directly on it, it has high tide. As the earth continues to rotate, the Pacific moves into the position where it has a high tide.

The sun and moon are not always on opposite sides of the earth. Some of the children may want to show how the tides would look when the moon and the sun are both on the same side of the earth (see Fig. 20.2) or when they are at right angles to the earth. See the neap tides as illustrated by the model in Fig. 20.3.

Fig. 20.2 Model illustrating the tidal bulges caused when sun's and moon's gravitational attraction is exerted on the same side of the earth (springtide).



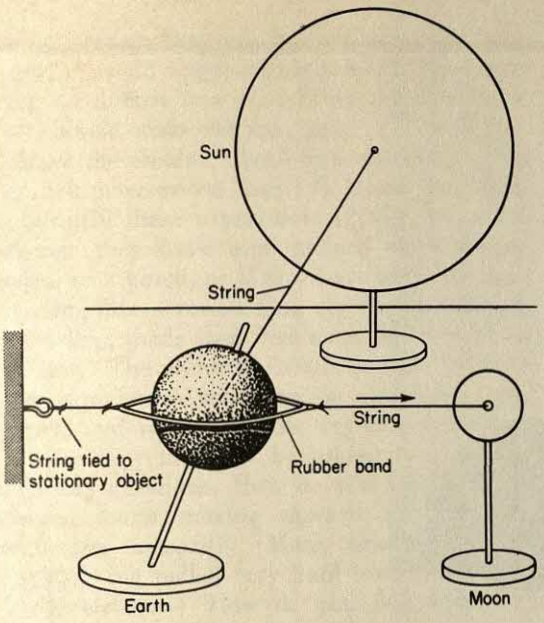


Fig. 20.3 Model illustrating the tidal bulges caused when sun's and moon's gravitational attraction is exerted at right angles to the earth (neap tide).

A string tied between the rubber band and a stationary object, as shown in Figs. 20.2 and 20.3, will prevent the globe from tipping over.

Children who live on the coast may enjoy keeping a record of the amount of change that occurs in the tide levels over a period of a month. They also may like to compare their records with the position of the sun and moon during this time. While they are keeping this record, call their attention to the difference in the time interval between tides. This variation of approximately 50 minutes each day corresponds to the change in time in moonrise. This is another evidence that the moon's gravitational attraction causes tides.

Children who have never seen the tides "come in" and "go out" find it difficult to grasp the relationship between tides and the moon's position in its orbit around the earth. Nevertheless these children, too, need to know that these relationships exist, because they constitute part of the evidence that makes astronomers believe that every heavenly body exerts a gravitational attraction upon every other heavenly body.

Read about Sir Isaac Newton and find out how his law of universal gravitation is stated. When did Newton live? How old was he when he stated this law? The content of this law is as follows:

> All bodies in the universe, from the heavenly bodies down to the smallest particles of matter, have a mutual attraction for one another. This force of attraction, acting between all bodies to pull them together, is directly proportional to the product of their masses, and varies inversely as the square of the distance between them.

When this law is converted into a mathematical formula, it looks like this:

$$F = \frac{Gmm'}{d^2}$$

(F = gravitational force; Gmm' = the product of their masses; d^2 = the square of the distance between the two bodies.) Newton's law of universal gravitation was so nearly correct that it has been accepted for over 200 years.

In 1905, at the age of 26 (see Fig. 20.4), Albert Einstein gave the world the first part of his theory of relativity, known as Einstein's Special Theory of Gravitation. This theory is a modification of Newton's law. Einstein found only a small error in Newton's law; but this difference was enough to explain some of the things that could not be explained by the original law of gravitation. In 1916, at the age of 37, Albert Einstein had expanded this theory and it became known as his General Theory of Relativity.

Read about the life and work of Albert Einstein. Be sure to have the class note his age when he gave the world his first theory, the Special Theory of Relativity.

The gravitational attraction between the sun and the planets holds the planets in their orbits. Newton's and Einstein's laws are used to determine the exact orbit of each planet. Ask the children whether they think these laws could be used to determine the orbit of the moon or the orbit of a man-made satellite.

8. How far does the earth's gravitational attraction extend beyond the surface of the earth?

Einstein called the area of an object's gravitational attraction *the gravitational field*. The area

Fig. 20.4 Einstein at age twenty-six. *Courtesy Lotte Jacobi.*

of attraction surrounding a magnet and an electric current is also called *a field.*

Challenge the children with questions like this: What proof, if any, do we have that, as an object moves farther and farther out into the earth's gravitational field, the effect of the earth's gravity decreases? (On television children will have seen the effects of decreased gravity on astronauts.)

9. What conditions are necessary for objects to escape the earth's gravitational attraction, or to force objects far out into the earth's gravitational field?

Discuss things like high jumping, throwing balls, airplanes, jets, and rockets in flight. Although all these objects leave the surface of the earth for only very limited distances, the children should be able to understand that force is the common factor that propels them away from the center of gravity. They should also be made aware of the source of energy that produces this force. Only with the energy that man has learned how to pack into a rocket and with the thrust created by the release of this energy, has he been able to produce a force great enough to overcome the earth's gravitational attraction. (See Chap. 25, Inquiry 6.)

10. What is meant by 7 G, 8 G, or even by 0 G? Why does a rocket, at take-off, produce an effect of 7 to 14 G's?

The children should try to find out what these terms mean. The amount of force exerted on an object on the surface of the earth is called 1 G. If a boy weighs 100 pounds on the surface of the earth, the earth attracts this boy with a force of 1 G. If this same boy lived on a planet with twice as much gravity, the planet would attract him with a force of 2 G and he would weigh 200 pounds. If this boy were being attracted with a force of 0 G, he would weigh nothing. Ask the children to figure what their weight would be at 0 G, 2 G, 3 G, 4 G, 7 G, and

14 G. Perhaps they can find out what a man in a rocket would weigh during take-off. Encourage them to discuss how they think this change in force would make the man feel.

Have the children recall experiences in which they felt more or less than 1 G. It may help them to identify these experiences if they are asked whether they have ever jumped off a diving board, or a porch, or if they have ever ridden in anything *like* a rocket that, on vertical take-off, or landing, made them feel uncomfortable in an odd way. The children should be able to name such experiences as riding on elevators, ferris wheels, and roller coasters. Try to get them to describe how they felt by asking some of the following questions: How do you feel when an elevator starts moving upward very rapidly, *accelerates upward?* (Much heavier and as though being pulled very hard toward the floor of the elevator.) How do you feel when the elevator starts moving downward very rapidly, *accelerates downward?* (Much lighter and as though the stomach were floating upward.)

Help the children plan an experiment to support their statements about their change in weight in upward and downward acceleration. Perhaps a group of them could investigate the possibility of using an elevator for a few minutes while they try to find out what the results really are. The only other materials they need are a bathroom scale and notebooks and pencils. Choose one child to stand on the scale. Note this child's weight when the elevator is standing still and when it ascends and descends. Have the group repeat the experiment several times and report the results to the entire class.

Acceleration produces the same effect as gravity. These two forces cannot be distinguished from each other. An elevator accelerating upward increases the weight of the passengers; if it is accelerating downward, it decreases the weight of the passengers. Here are some simple arithmetic problems for the children to solve:

1. **A boy weighs 100 pounds. The earth's gravity attracts him with 1 G. As he accelerates upward, he weighs 500 pounds. How many G's does he experience? (5 G)**
2. **On upward acceleration a boy, who normally weighs 100 pounds, finds that the scale records his weight as 110 pounds. How many G's does this boy experience? (1.1 G)**
3. **If a boy, who weighs 100 pounds, finds that he weighs 50 pounds, how many G's does he experience? (0.5 G)**
4. **If this 100-pound boy, on downward acceleration, finds that he weighs 90 pounds, how many G's does he experience? (0.9 G)**
5. **If the children do the experiment on the elevator, have them figure the G's the child standing on the scales experienced in his ride up and down on the elevator.**

Scientists have done experiments with men to see how they feel at 0 G and at 8 G or more G's. They found that flying at high speed in a controlled pattern produces, for a very short period of time, a condition of 0 G. In one experiment, many G's were experienced by men who were propelled forward very rapidly on a vehicle like a sled. A number of periodicals have articles about this experience. Have the children find these periodicals in the library and read about these tests. Scientists carry on experiments like this one in order to find out how changes in G affect men. Information from experiments like these is now being used in space explorations.

11. What relationship, if any, exists between magnetic fields, electric fields, and gravitational fields?

See Chap. 17, and Chap. 18, Inquiry 4, for experiences and learnings about magnetic poles attracting and repelling and electric charges attracting and repelling.

Compare the mathematical formulas for the forces of gravitation, electricity, and magnetism. The children need not know how to use these formulas to note their similarity. It would be best to have some of the children find the formulas in physics books. Some of the fast learners in the group may even want to explore the mathematics involved.

1. **Two bodies will attract each other with a force that is figured by Newton's formula: $F = \frac{Gmm'}{d^2}$, where F is the force of gravitational attraction, G is the gravitational constant, mm' is the product of the masses of the two bodies, and d^2 is the square of the distances between the two bodies.**
2. **Two unlike electric charges will attract each other with a force that physicists find by this**

formula: $F = \frac{Cqq'}{d^2}$, where F is the force of electrical attraction, C is a constant, qq' is the product of the amounts of the unlike charges (the negative charge and the positive charge), and d^2 is the square of the distances between the unlike charges.

3. **Two unlike magnetic poles will attract each other with a force that is found by this formula: $F = \frac{KMM'}{d^2}$, where F is the force of magnetic attraction, K is a constant, MM' is the product of the strengths of the unlike poles (the north and south magnetic poles), and d^2 is the square of the distance between the unlike poles.**

Have the children read about Einstein's work on what he called the *Unified Field Theory*. Einstein saw a similarity between the formulas for these three forces. He saw that all three could attract but only two seemed to repel. He spent many years working on the hypothesis that there might be one law which would apply to all three. Einstein was also interested in discovering why there was no known repelling force for gravitation. If such a repulsive force did exist, or even if one could be produced, it would be one way to solve the problem of how to leave the earth's gravitational attraction.

There are many problems like this one for which scientists do not have the answers. Scientists in many parts of the world are working and thinking about these problems. Children need to know that many important problems remain to be solved, and some of their classmates may be the people who will help to solve them. Here again is an opportunity to emphasize that often it is the young scientist who pushes back the barriers of the unknown. Galileo, Newton, and Einstein are excellent examples of young men who succeeded in doing this.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Wherever people stand on the earth, their feet touch the ground and their heads are in the air. *Up* is away from the earth. *Down* is toward the center of the earth.

2. Things fall down. They fall to the floor; they fall to the ground, or earth. The earth has a force that pulls, or attracts, things toward its center. This force is called *gravity*. We cannot see gravity but we can see what it does.

3. If similar objects of different weights are dropped from the same place at the same time, they will reach the earth at the same time.

4. People depend upon gravitational attraction to keep things where they are placed. The earth's gravitational attraction causes all objects on the earth to have weight.

5. All heavenly bodies have gravitational attraction. Our weight is a measure of the earth's gravitational attraction. Our weight on another heavenly body would be a measure of its gravitational attraction. Different heavenly bodies have different amounts of gravitational attraction. The amount of gravitational attraction depends upon the mass of a heavenly body. They say that the force of gravity is proportional to the mass of the body (quantity of matter in it).

6. Size (volume) and mass do not mean the same thing. *Size* or volume refers to the space occupied by the body (width, length, and height). *Mass* refers to the total amount of matter in the object. *Density* describes the concentration of matter or the amount of matter in a given volume (cubic inch or cubic centimeter).

7. Every object in the universe attracts every other object. The amount of gravitational attraction between two objects depends upon the mass of the objects and the distance between them. Tides are caused by the gravitational attraction of the moon and the sun on the earth. The gravitational attraction between the sun and the planets determines the orbits of the planets. Gravitational attraction between the earth and the moon and between the earth and a man-made satellite determines the orbit of each. Newton was the first man to state the law of universal gravitation. Einstein, at the age of 26, found errors in this law and corrected them in the theory called *Einstein's Special Theory of Gravitation.*

8. The earth's gravitational attraction extends far beyond the surface of the earth. This area of attraction is called the *gravitational field.* Gravitational attraction decreases with an increase in distance from the earth.

9. Man has learned to use force to send objects far out into the earth's gravitational field. Some objects have escaped from the earth's gravitational field.

10. 7 G, 8 G, or 0 G is the physicist's way of expressing the gravitational effect of acceleration on an object. Acceleration and gravity produce the same effect and cannot be distinguished from each other. The acceleration of a rocket at take-off adds to the gravitational effect of the earth. *Experiments prove* that man can stand 0 G to 8 G and probably even more than that.

11. Much knowledge remains to be discovered. Even great scientists like Einstein ask themselves questions about which there are no known answers. The barriers to more complete knowledge raised by these unsolved problems are under attack by scientists in all parts of the world. Some scientists believe that these barriers may be conquered. The work of the scientist is difficult, but it is also challenging and rewarding.

Chapter Twenty-One

Machines

INQUIRIES

1. What are machines? Why do people use machines? What are the fundamental machines? How is a machine's mechanical advantage determined?

2. How are lawnmowers, bicycles, automobiles, and airplanes related to the six simple machines?

3. How do power lawnmowers differ from hand lawnmowers? How do motorcycles differ from bicycles?

4. What sources of energy now operate complex machines?

1. What are machines? Why do people use machines? What are the fundamental machines? How is a machine's mechanical advantage determined?

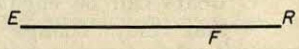
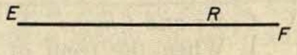
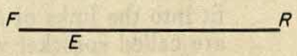
Some experiences for this inquiry appear in Table 21.1. Pupils should be encouraged to do personal and group research and experimentation, to set up quantitative measurements and controls, and to develop concepts from the results of their work. The pupils' research should reveal an almost inexhaustible supply of information and experiments.

Table 21.1

SIMPLE MACHINES

Findings	Examples and Materials That Can Be Used
I. *Wheels That Roll*	
1. An object can be dragged or pushed *more easily and faster* on wheels than it can without wheels.	Carts, roller skates, and toys with wheels
II. *Wheels Reduce Friction*	
1. When rollers, ball bearings, or wheels are used between the object to be moved and the surface over which it is to be moved, friction between them is reduced.	
2. Because they reduce friction, rollers, ball bearings, and wheels make the work of moving objects *easier and faster*.	
III. *Wheels and Belts*	
1. One wheel can be made to turn other wheels by connecting it to the others with endless belts.	Different sized spools connected by rubber bands and free to turn on nails set in a board
2. Wheels connected by untwisted endless belts all turn in the same direction.	
3. Wheels connected by belts containing a half twist will turn in opposite directions.	
4. When wheels of the same size are connected by belts, all the wheels move at the same speed.	
5. When wheels of different sizes are connected by belts, the smaller wheels will turn faster than the larger wheels.	
IV. *Wheels with Teeth*	
1. Wheels with teeth are called gears.	Hand egg beaters and key-wind alarm clocks
2. The teeth of some gears fit directly into or engage the teeth of other gears.	
3. When the teeth of two gear wheels are engaged, one gear can turn the other gear.	
4. A gear that turns clockwise turns the gear it engages counterclockwise. The reverse is also true.	
5. When a larger gear drives a smaller gear, the smaller gear turns faster.	Egg beater
6. When a smaller gear drives a larger gear, the larger gear turns more slowly.	Clock gears
7. Gears can be engaged in such a way that they change the *direction of motion*.	Egg beater
V. *Gears and Chains*	
1. When the teeth of gears are built to fit into the links of a chain, these gears are called sprocket wheels.	Bicycle

***Table 21.1* (*cont.*)**

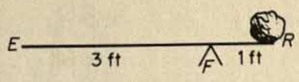
2. Sprocket wheels connected by an endless chain work together just the same as wheels connected by an endless belt.	
3. There is less slippage between sprocket wheels and chain than between wheels and belt.	
VI. *Simple Machines*	
1. There are six simple machines.	They are the lever, wheel and axle, pulley, inclined plane, screw, and wedge.
2. Simple machines are mechanical devices.	
3. In each simple machine an applied force (*effort*) moves a load (*resistance*).	
4. Most simple machines have a *mechanical advantage.* Mechanical advantage is written *MA*. See 7 and 8 in this list.	The mechanical advantage of a simple machine is a mathematical relationship between the effort and the resistance.
5. Because of its mechanical advantage, a simple machine *magnifies* the effort exerted on it so that the effort *seems* larger. The resulting effect of a simple machine's mechanical advantage is that a small effort can move a large resistance.	
6. Simple machines are able to move the resistance through a distance called the *resistance distance.* They do this by exerting an effort through a distance called the *effort distance.*	
7. Each simple machine has a mathematical formula by which (*disregarding friction*) its mechanical advantage can be figured.	
8. The general formula for figuring the mechanical advantage of a simple machine is stated in either one of two ways: $MA =$ resistance (R) divided by effort (E). $MA =$ effort distance (ED) divided by resistance distance (RD).	
VII. *Lever*	
1. Levers are found in many shapes and sizes.	Crowbar, hammer, shovel, wheelbarrow, fishpole, scissors, pliers, tongs
2. All levers have three parts: a fulcrum, an effort arm, and a resistance arm. The one point of a lever that does not move is called the fulcrum.	
3. The three parts of a lever can be arranged in three different ways depending on how the lever is to be used.	*First class lever*  *Second class lever*  *Third class lever* 

4. The more convenient mathematical formula for figuring the mechanical advantage of a lever is:
   MA = *effort distance* divided by *resistance distance.*
   The effort distance is measured from the effort to the fulcrum; the resistance distance, from the resistance to the fulcrum.

5. First and second class levers *magnify effort*; the third class *magnifies speed and distance.*

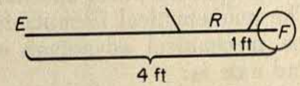
In order to compare the mechanical advantage of the three classes of levers shown in number three above, assume that each lever is 4 feet long and divided as follows:

Example of first class lever (crowbar)



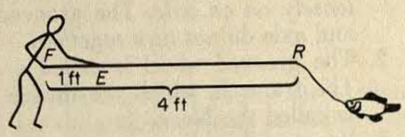
MA = 3 divided by 1
MA = 3

Example of second class lever (wheel barrow)



MA = 4 divided by 1
MA = 4

Example of third class lever (fishpole)



MA = 1 divided by 4
MA = $\frac{1}{4}$

In the specific examples of the three levers compared in 4 above, the first and second class levers magnify the effort; the first magnifies the effort by 3 and the second by 4. The mechanical advantage of the third class lever above is $\frac{1}{4}$. In this lever effort is lost. What is magnified? (Speed and distance.) The fish is *quickly* lifted through a *long distance.*

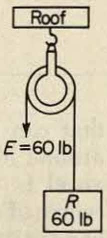
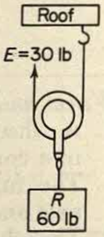
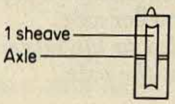
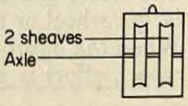
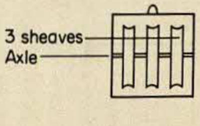
VIII. *Wheel and Axle*

1. A wheel is a lever that can be moved in a complete circle around its fulcrum. The fulcrum of a wheel is called the axle and it is at the center of the wheel.
2. The wheel is larger than the axle. Wheel and axle *always turn together.*
3. The wheel and axle form a simple machine.
4. The effort can be applied either to the larger wheel or to the smaller axle.
5. When *the effort is applied to the larger wheel,* effort *is gained at the axle.*

Examples of wheel and axle machines are the windlass, waterwheel, doorknob, pencil sharpener, screwdriver, windmill, and potter's wheel.

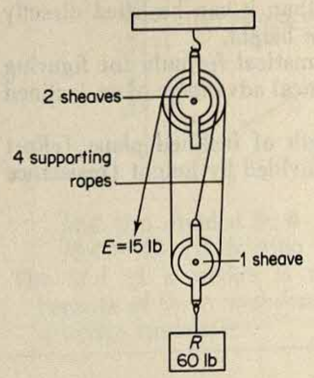
The effort applied to move the wheel one turn rotates the smaller axle once. The effect is like concentrating the effort in a smaller space (the axle). As a result effort is gained. Because effort is gained, the axle can move a larger resistance slowly. (Windlass, potter's wheel, steering wheels.)

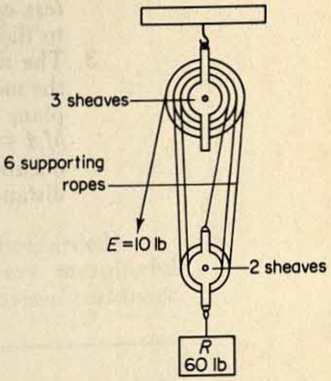
***Table 21.1* (*cont.*)**

6. *When effort is applied to the axle, speed and distance are gained.*	The effort applied to move the axle one turn also makes the wheel turn once. Because the wheel is larger than the axle, the rim of the wheel travels *farther*. The effect is that the distance traveled by the wheel is a magnification of one turn of the axle. As a result distance and speed are gained, when effort is applied to the axle. (Electric fans and food mixers, and vehicles where wheels are turned by turning the axle.)
7. How much distance and speed are gained or how much effort is magnified depends on the *mechanical advantage* of the specific wheel and axle used. 8. The mathematical formula for figuring the mechanical advantage of a wheel and axle is: $MA =$ radius of wheel divided by radius of axle.	
IX. *Pulley* 1. A pulley is a grooved wheel that *turns loosely on an axle*. The grooved wheel and axle do *not turn together*. 2. The grooved wheel is called a *sheave*. The frame in which the sheave rotates is called the *block*. 3. Ropes and cables are used with pulleys. 4. Pulleys may be either *fixed or movable*.	*Examples:* *Fixed pulley*. This pulley (below, left) does *not travel* with the resistance. *Movable pulley*. This pulley (below, right) *travels* with the resistance. *Both ends* of the rope support the resistance. This pulley has two supports.  
5. Pulleys may be single, double, triple etc. depending on how many sheaves (wheels) there are on one axle.	*Examples:* *Single pulley*  *Double pulley*  *Triple pulley* 

6. When fixed and movable pulleys are combined, they are called a *block and tackle*.

Examples:





7. *Fixed pulleys only change work direction.* They have no mechanical advantage.

Pulling down on a rope raises a flag on a flagpole.

8. *Movable pulleys have a mechanical advantage.*
9. Three ways for figuring the mechanical advantage are:
   MA = the number of supporting ropes;
   MA = the *effort distance* divided by the *resistance distance;*
   MA = *resistance* divided by the *effort.*
10. The effort needed to move a given resistance *decreases* as the number of ropes in a pulley system *increases.*

The following examples show how to figure the *MA* for the pulley systems previously shown.

Example 1.

The *MA* for the movable pulley shown in 4 above is 2 (2 ropes). A 30 pound effort magnified by this *MA* of 2 can lift the 60 pound resistance.

Example 2.

The *MA* for the first diagram of a block and tackle shown in 6 above is 4 (4 ropes). A 15 pound effort magnified by this *MA* of 4 can lift the 60 pound resistance.

Example 3.

The *MA* for the second diagram of a block and tackle shown in 6 above is 6 (6 ropes). A 10 pound effort magnified by this *MA* of 6 can lift the 60 pound resistance.

11. Movable pulleys are used because their *MA* magnifies the effort applied. At the same time, the resistance moves only a small distance and very slowly. Pulleys are said to trade distance for effort.

X. *Lever Group of Simple Machines*

1. The lever group contains three simple machines. The lever, the wheel and axle, and the pulley are alike in many ways.

Lever, wheel and axle, and pulley

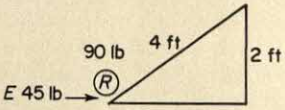
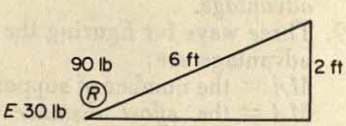
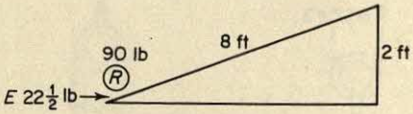
2. The word, *leverage,* is commonly used by workmen when they are referring to the mechanical advantage of wheels and pulleys as well as levers.

XI. *Inclined Plane*

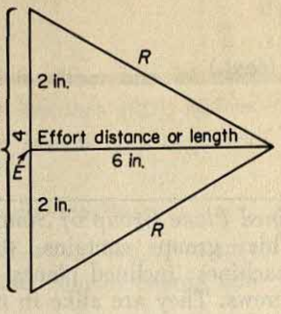
1. An inclined plane is a flat surface raised at one end.

Ramps, slopes, stairs etc. are examples of inclined planes.

***Table 21.1* (*cont.*)**

2. A resistance can be *moved up* an inclined plane to a desired height *with less effort* than it can be lifted directly to the same height.	
3. The mathematical formula for figuring the mechanical advantage of an inclined plane is: *MA* = length of inclined plane (effort distance) divided by height (resistance distance).	The following examples show how to figure the mechanical advantage of three inclined planes. In each example, a 90 pound barrel is to be raised 2 feet above the ground. *Example 1.*  The *MA* for this inclined plane is 4 feet divided by 2 feet or 2. A 45 pound effort magnified by this *MA* of 2 will move the 90 pound resistance. *Example 2*  The *MA* of this second inclined plane is 6 feet divided by 2 or 3. A 30 pound effort magnified by this *MA* of 3 will move the 90 pound resistance. *Example 3.*  The *MA* for this third example is 8 feet divided by 2 or 4. A 22½ pound effort magnified by this *MA* of 4 will move the 90 pound resistance.
4. An object moves down an inclined plane *with less speed* than when it falls directly down. It also travels a *longer* distance down the inclined plane than when it falls directly down. The longer the inclined plane, the less the speed will be.	Children's slides, vehicles *moving down hills.*
XII. *Wedge*	
1. A wedge is a double inclined plane.	Some common wedges are knives, needles, axes, can openers, cold chisels etc.

2. Wedges are used to pierce, split, cut and push things apart. Effort is needed *to move the wedge into the* resisting object.
3. The mathematical formula for figuring the mechanical advantage of a wedge is:
   MA = length of the inclined plane (effort distance) divided by the distance between the two inclined planes (resistance distance).
4. Because a wedge magnifies the effort, it is easier to pry, split, or cut an object with it than to pull the object directly apart.



$MA = 6$ divided by 4
$MA = 1\frac{1}{2}$ (if friction is disregarded)

The MA of a wedge is not very meaningful because of the *tremendous frictional resistance* a wedge encounters.

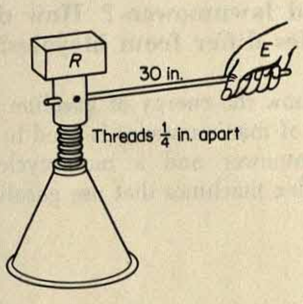
XIII. *Screw*

1. A screw is a specialized inclined plane. It is a twisted or rolled up inclined plane.
2. Screws are used to lift objects, to hold objects together, and to carry things from place to place.
3. The rotary motion of a turning screw is changed into a straight line motion.
4. Screws need levers to turn them.

Some common screws are a wood screw, a bolt, a screwjack, a brace and bit, and an auger.

Jackscrew, wood screw, and so on.

Screw. . .turned by. . .	Lever
wood screw	screw driver
bolt	wrench
jackscrew	bar handle
brace and bit	brace



5. The mechanical advantage of a screw is:
   MA = distance the effort moves divided by the distance the resistance moves (the distance between the threads of the screw or pitch).

The effort applied to this jackscrew moves through the circumference of a circle which has a 30-inch radius.

$C = 2\pi r$
$C = 2 \times 3.1416 \times 30$
$C = 188.50$ inches (effort distance)

The effort distance for this screwjack is 188.50 inches. Because the threads in this screwjack are $\frac{1}{4}$ inch apart, the resistance will be lifted (moved) $\frac{1}{4}$ inch for each complete revolution of the effort. This is the distance the resistance moves.

$MA = 188.50$ divided by $\frac{1}{4}$
$MA = 754.00$

***Table 21.1* (*cont.*)**

	This means a resistance or weight that is 754 times as great as the effort used can be raised with this screwjack. With this screwjack a 2 pound effort could raise a 1508 pound weight.
XIV. *Inclined Plane Group of Simple Machines* 1. This group contains three simple machines: inclined planes, wedges and screws. They are alike in many ways.	Inclined plane, wedge, and screw.

2. How are lawnmowers, bicycles, automobiles, and airplanes related to the six simple machines?

Have a bicycle and a hand lawnmower brought into the classroom. Ask the pupils to list any simple machines they can see in the lawnmower and bicycle. (They should discover that each contains two or more of the six simple machines. Simple machines are combined to form complex machines.)

Discuss the automobile and airplane as examples of complex machines.

3. How do power lawnmowers differ from hand lawnmowers? How do motorcycles differ from bicycles?

Discuss how the energy of gasoline instead of the energy of man's muscles is used to operate a power lawnmower and a motorcycle. Discuss other complex machines that use gasoline energy to supply the effort to operate them (automobiles, airplanes, and so on).

4. What sources of energy now operate complex machines?

The pupils should be able to list these sources of energy (muscles, wind, falling or moving water, steam, electricity, fuels such as fuel gas, gasoline, and diesel oil, nuclear energy, and solar energy).

Ask students to select one energy source and to prepare a report on how the energy is released. Encourage them to include in their report an explanation of how it is controlled and applied to operate a specific machine. Also encourage them to prepare charts to accompany their explanation and, whenever safety permits, to include a simple demonstration.

See Chapter Summary of Process Skills on front and back endpapers of this book for process skills that can be practiced while developing the inquiries in this chapter.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. There are six simple machines. They are the lever, wheel and axle, pulley, inclined plane, wedge, and screw. Simple machines are mechanical devices. In each simple machine an applied force (effort) moves a load (resistance).

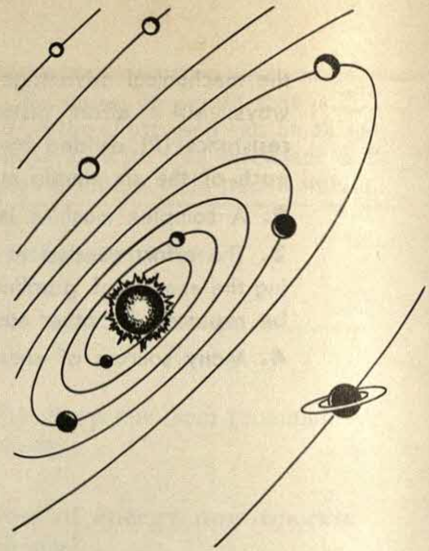
Most simple machines have a mechanical advantage (*MA*). Because of its mechanical advantage, a simple machine *magnifies* the effort exerted on it so that the effort *seems larger.* The resulting effect of a simple machine's mechanical advantage is that a small effort can move a large resistance. Simple machines move the resistance through a distance called the *resistance distance.* It is done by exerting an effort through a distance called the effort distance.

For each simple machine there is a mathematical formula by which (disregarding friction) its mechanical advantage can be figured. The general formula for figuring the mechanical advantage of a simple machine is stated in either one of two ways: *MA* = effort distance (*ED*) divided by resistance distance (*RD*). *MA* = resistance (*R*) divided by effort (*E*). (See Table 21.1 for specific learnings for each of the six simple machines.)

2. A complex machine is composed of two or more simple machines.

3. The effort needed to operate some complex machines is supplied by releasing the energy of gasoline and applying it to the machine. Muscle energy can be replaced by other sources of energy.

4. Many sources of energy are used to operate machines.



Chapter Twenty-Two

The Universe

The Solar System

INQUIRIES

1. What kind of heavenly body is the moon? Why does the moon look as if it has a face? What makes the moon shine?

2. Why on some nights do we see a full moon and on other nights a half- or a quarter-moon? Why is one moon day as long as 14 earth days? Why is one moon night as long as 14 earth days?

3. Why do astronomers think that there can be only simple forms of life on Mars? What do they believe about the possibilities of life on other planets in the solar system?

4. How many different kinds of bodies are there in our solar system? What do astronomers know about their size, distance from the sun, and composition?

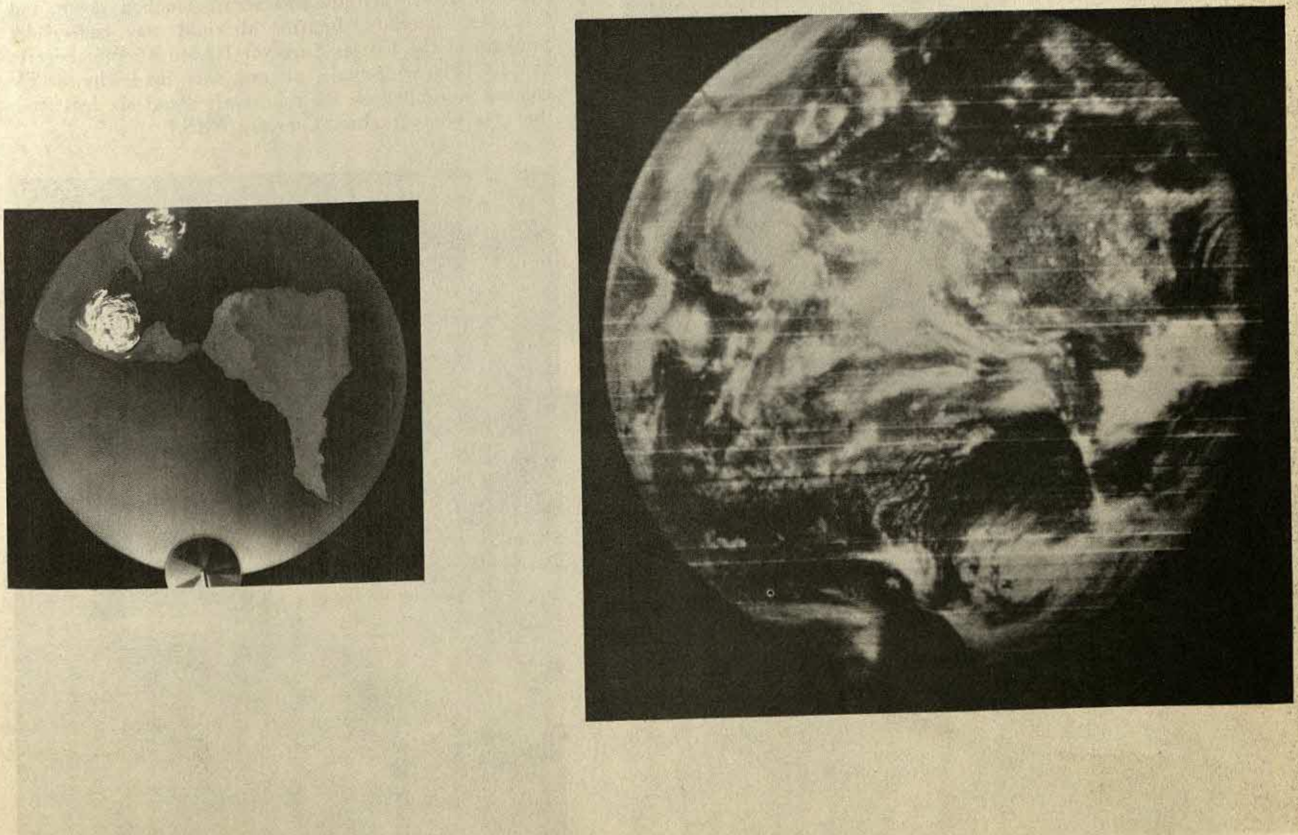
This skeletonized chapter features inquiries, tables of information, scientific findings, and a picture supplement. See Figs. 22.1 through 22.7. Six of the photographs are electronic products of unmanned space probes within the solar system. The spacecraft were programmed to do many things. The instruments on board scanned the area, stored the information, and on a command signal, transmitted the information to earth by radio telemetry.

In the late 1960's pictures of the moon, the earth, and Mars gave new dimensions to the study of these heavenly bodies. Future manned and unmanned probes will continue to expand our knowledge of the solar system.

For this reason teachers and pupils need a reliable source for up-to-date information in this subject area. The Educational Services Division of the National Aeronautics and Space Administration (NASA) will furnish free of charge teaching units, pictures, and movies. NASA also has a very worthwhile spacemobile lecture and demonstration, which, without charge and on request, they will schedule to visit a school system. See page 60 for complete address.

To emphasize how rapidly discoveries about the solar system are being made, compare the data given in Table 22.1 with similar data published both *before* and *after* 1970. Table 22.1 reflects only the best information available at the time of its publication. From current periodicals start a bulletin or clipping file of pictures and articles about the solar system. Compare the information in them with that in Table 22.1.

Fig. 22.1 Nearly all of South America is outlined on the right side of this striking photograph made by the Navy's DODGE satellite on September 18, 1967. From 22,300 miles, for the first time, the colors of the earth were recorded (this photograph is reproduced in its original color on the cover of this book). Above South America is a string of the larger islands of the West Indies. A good portion of Central America, the east coast of the United States, the West coast of Mexico, and, on the extreme left, part of the California coast and Gulf of California are also visible. The larger white circular mass in the Gulf of Mexico is Hurricane Beulah just before she struck the Texas-Mexican Border. Up the coast appear to be some of the remains of Chloe and Doria. The schematic photo (below left) shows North and South America as they appear on the actual photograph under cloud cover. The identified hurricanes are sketched to help orient the viewer. *Courtesy United States Department of Defense.*



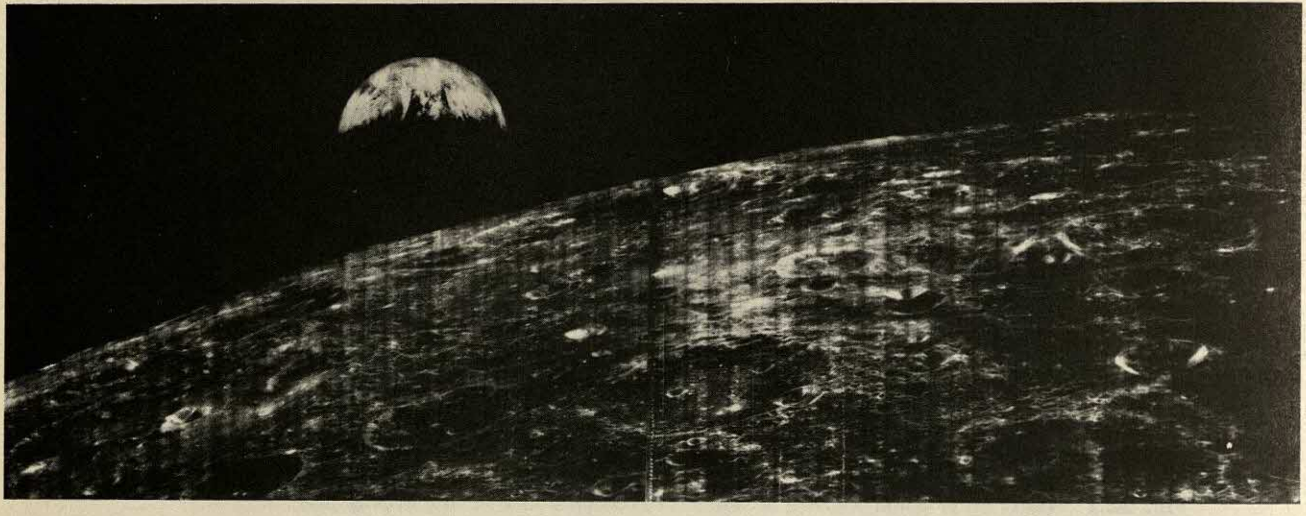


Fig. 22.2 The small crescent earth is the first view of the earth taken by a spacecraft from the vicinity of the moon. *Courtesy NASA.*

Fig. 22.3 The moon. *Courtesy Lick Observatory.*

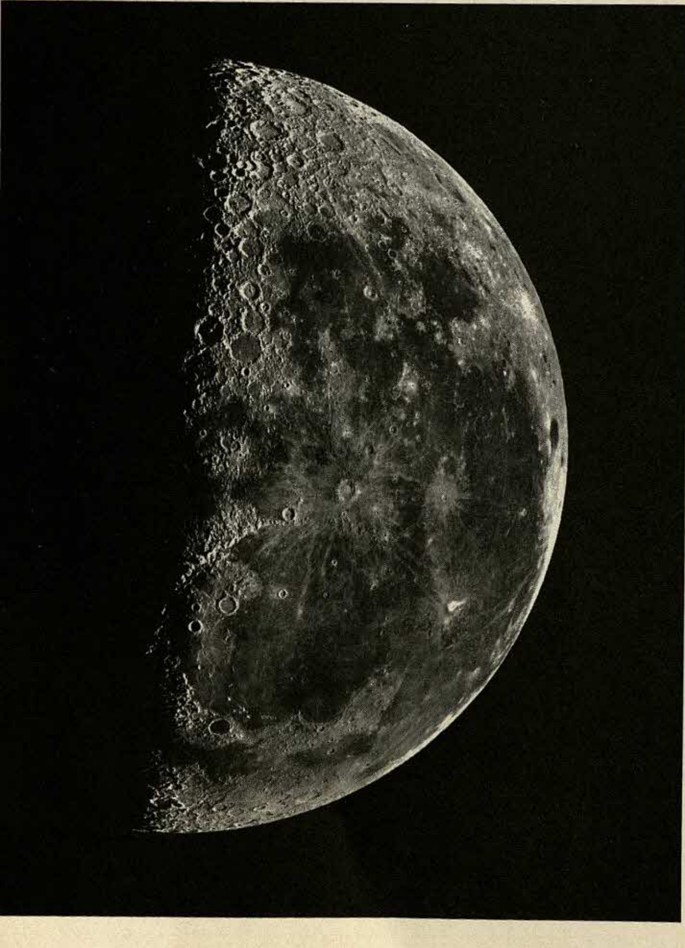
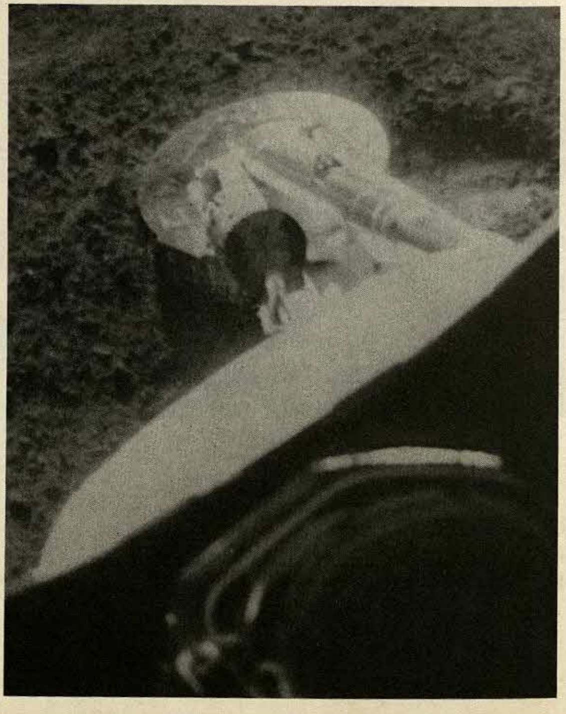


Fig. 22.4 Television picture from U.S. spacecraft Surveyor V shows landing foot resting on the lunar surface. Loose lunar material covers part of the 12-inch-diameter foot. The moon soil apparently was thrown onto the foot when the spacecraft touched down and "skidded" laterally. Imprint at right was caused by pressure of the foot as Surveyor landed (September 10, 1967). This wide-angle picture was made by a TV camera positioned on the spacecraft about six feet from the area photographed. *Courtesy NASA.*



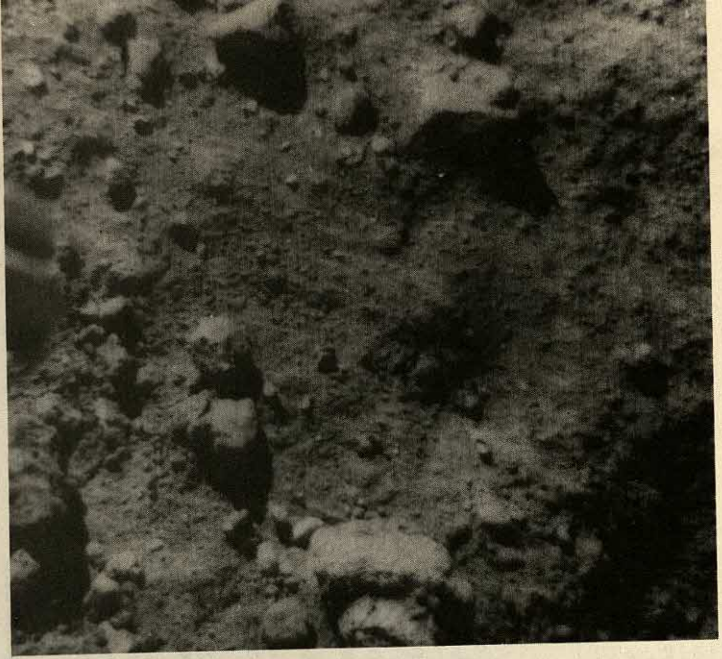


Fig. 22.5 A small area of the lunar surface strewn with loose fragments scattered by Surveyor V as it landed in a small lunar crater. End of deployment mechanism for alpha scattering instrument can be seen at left center. The Surveyor V spacecraft (the fifth in the series of NASA's soft lunar landing program), like the four previous Surveyors, had the mission of performing a soft landing in the Apollo area of interest on the Moon and to take television pictures of the lunar surface around its landing site. *Courtesy NASA.*

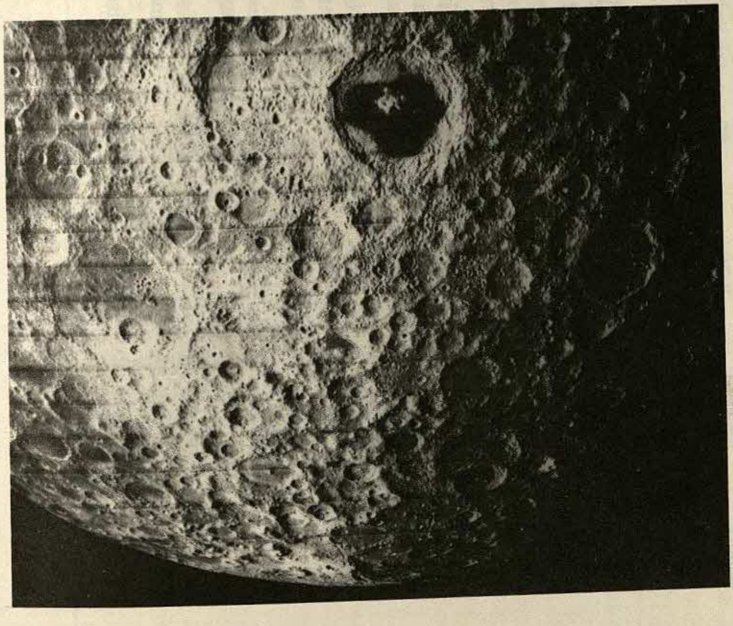


Fig. 22.6 The hidden side of the Moon photographed February 19, 1967 by the Lunar Orbiter III in its mission to photograph potential manned landing sites on the Moon. The photograph was taken from an altitude of approximately 900 miles at a position 250 miles south of the lunar equator. The curved southern horizon stretches to within about 400 miles of the south pole. The picture spans approximately 700 miles along its northern edge near the equator. The sun is on the left. What can be seen? Close your eyes for a second. Turn the book upside down and look again. Do you see the same things? The prominent crater filled with dark material near the center of the photograph is about 150 miles in diameter. Over much of its circumference the rim of this crater has slumped inward in a manner similar to that observed in many places in the lunar frontside craters. *Courtesy NASA.*

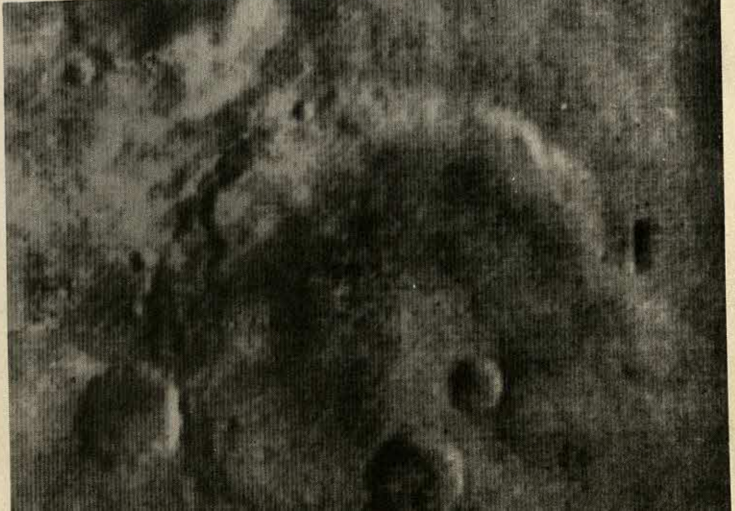


Fig. 22.7 A photographic representation of digital data radioed from Mars by the Mariner IV spacecraft. Mariner photographed Mars on July 14, 1965, just prior to its closest approach of about 6000 miles from the planet. Do you see the round spots as craters or hills? Try looking at the picture from different angles. *Courtesy NASA.*

Table 22.1

INFORMATION ABOUT THE PLANETS

Planets	Number of Satellites (moons)	Diameter at Equator (mi)	Average Distance (million mi)	Period of Revolution, or Length of Year	Period of Rotation, Length of Day	Surface Gravity Compared with Earth	Average Temperature (degrees Fahrenheit)	Kind of Gases in Atmosphere	Water	Diameter Compared with Earth	Period of Revolution Compared with Earth Year	Amount of Heat and Light Compared with Earth
Mercury	0	3,100	36	88 days	88 days	0.25	780	No atmosphere	None	0.39	0.24	7.50
Venus	0	7,600	67	225 days	30 or 225 days (?)	0.85	60, or 800 to 1,000	Nitrogen; neon; water vapor	5% in atmosphere	0.97	0.62	2.00
Earth	1	7,900	93	365 days	24 hr	1.00	60	Oxygen; nitrogen; carbon dioxide	Covers ¾ of surface	1.00	1.00	1.00
Mars	2	4,200	141	687 days	24.5 hr	0.37	−200 to 75	Some oxygen; frozen carbon dioxide; water vapor; ammonia; methane	Edges of polar caps contain frozen water	0.53	1.90	0.50
Jupiter	12	88,700	483	12 yr	10 hr	2.64	−120 to −170	Poison gases: ammonia and methane	?	11.98	12.00	0.037
Saturn	10	75,000	886	30 yr	11 hr	1.17	−140 to −250	Poison gases: ammonia and methane	?	9.36	30.00	0.011
Uranus	5	32,400	1,785	84 yr	11 hr	0.92	−180	Poison gas: methane	?	4.08	84.00	0.003
Neptune	2	30,900	2,792	165 yr	16 hr	1.12	−210	Poison gas: methane	?	3.89	165.00	0.001
Pluto	0 (?)	3,600 (?)	3,670	248 yr	6½ days	(?)	−380	Poison gas: (?)	?	0.46	248	0.0006

Table 22.2

COMPARATIVE SIZES AND DISTANCES FOR MODELS OF THE SOLAR SYSTEM

			Scale no. 1* (1 in. = 1,000 mi)		Scale no.2† (1 in. = 1,000,000 mi)	
Name	Diameter (mi)	Distance from Sun (million mi)	Size (approx.)	Distance (approx.)	Size (approx.)	Distance (approx.)
Sun	865,000	—	72 ft	—	0.9 in.	—
Mercury	3,100	36	3 in.	½ mi	Too small to make	1 yd*
Venus	7,600	67	7½ in.	1 mi	Too small to make	1 yd, 31 in.
Earth	7,900	93	8 in.	1½ mi	Too small to make	2 yd, 21 in.
Mars	4,200	141	4 in.	2¼ mi	Too small to make	3 yd, 33 in.
Jupiter	88,700	483	89 in.	7½ mi	Too small to make	13 yd, 15 in.
Saturn	75,000	886	75 in.	14 mi	Too small to make	24 yd, 22 in.
Uranus	32,400	1,785	32 in.	28 mi	Too small to make	49 yd, 21 in.
Neptune	30,900	2,792	31 in.	44 mi	Too small to make	77 yd, 20 in.
Pluto	3,600 ?	3,670	3½ in.	58 mi	Too small to make	101 yd, 34 in.

* The same scale is used for both size and distance because it is the best way for children to obtain a true concept of the vastness of the solar system.

† These converted distances are given in yards instead of feet because yardage can be used by children on the school football field.

How much of the information is different from the information in the table?

Have the pupils make careful observations of the photographs in this chapter. Also have them study the most recent photographs which they have collected. Then ask the children to describe and draw inferences (hypotheses) from what they see in each photograph. Through questions and discussions make them aware that their inferences are based upon their past experiences with direct views of the earth and the moon. Also discuss why direct observations are better than indirect ones (in this case interpretations made from photographs). Include in the discussion the value of manned space explorations.

Table 22.2 will be useful if models of the solar system are to be made.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. The moon is round like the earth. The moon revolves around the earth. The moon is called the earth's *satellite* because it revolves around the earth. The dark areas on the moon are shadows. We see objects by reflected light. The moon shines because it reflects the light from the sun.

2. The moon revolves in such a way that the same side always faces the earth. The far side of the moon has never been seen from the earth. It has been seen, photographed, and televised by astronauts. From earth we see only the lighted part of the moon that faces the earth. Sometimes we can see all the lighted part of the moon; sometimes we see only a half or a quarter of the lighted part; sometimes, we cannot see any lighted part at all. These changes are caused by the moon's revolution around the earth. The changes in the shape of the visible part of the moon are called *phases.* Day and night on the moon are about 14 earth days long.

3. Scientists think that conditions similar to those found on the earth must be present on a planet if the planet is to support life as we know it. Some astronomers think that lower forms of plant life may exist on Mars. They believe that higher forms of plant life cannot exist on Mars because it lacks free nitrogen and bodies of water. Present knowledge about the other planets in our solar system makes it seem that even lower forms of life would find existence on them unlikely.

4. Our solar system consists of one *star* (the sun); nine known *planets* (six of which have one or more *satellites*), *asteroids, comets,* and *meteors.* Stars give off their own light and heat. The sun is the source of light and heat for the planets, satellites, comets, and asteroids; they shine by reflected light. Planets, asteroids, and comets revolve around the sun. Satellites revolve around the planets. The earth as it revolves around the sun pulls in meteors. Planets rotate on their axis as well as revolve around the sun.

The most acceptable theory regarding the origin of the solar system is the cosmic cloud theory. According to this theory, the sun and the planets evolved form a cosmic cloud consisting of dust and gases. A cometary cloud, lying beyond the orbits of the planets, is believed to be the source of comets. One recent theory regarding the composition of comets states that a comet is a conglomerate containing an icy core surrounded by a porous crust of meteoric materials. Most of the meteors that are drawn into the earth's atmosphere are believed to originate in a huge meteoric cloud that swings in an orbit around the sun. Some of the larger meteors may be the remains of one or more disintegrated planets. Meteoric showers are believed to be caused by the dust trails left by comets that have passed close to the earth.

Chapter Twenty-Three

Beyond the Solar System

INQUIRIES

1. What heavenly bodies are beyond the solar system?
2. What is the Milky Way?
3. What is beyond the Milky Way Galaxy?
4. What are some of the instruments astronomers use to increase their "seeing power"?

This chapter has been skeletonized. Lists of major and minor inquiries and some of the basic conclusions that astronomers have made are included. A summary of scientific findings also is given. Much of the information the children need for making their investigations can be found in children's science textbooks, trade books, and encyclopedias.

1. What heavenly bodies are beyond the solar system?

Knowing the answers to the following questions will help teachers guide pupils in their search for information.

1. How many stars can we see in the evening sky? (About 2000; about 4000 different stars as visible during the year; 6000 stars are visible from different parts of the earth.)
2. How long has the starlight we will see tonight been traveling earthward? (See Table 23.1.)
3. Which of the bright stars are larger and which ones are smaller than our sun? (See Table 23.2.) Antares is so large that if it were placed in the center of our solar system, it would more than fill the space occupied by the orbits of Mercury, Venus, Earth, and Mars.
4. Which stars are cooler than our sun and which are hotter? (See Table 23.2.)
5. Why do stars twinkle and seem to have points?
6. Why do some stars appear to rise in the east and set in the west?
7. Why do other stars never rise or set?
8. Why do people in the Northern Hemisphere never see some stars that people in the Southern Hemisphere see?
9. Where are the stars in the daytime?
10. Why do we see different constellations during the different seasons? See Fig. 23.1.

Table 23.1

DISTANCE IN LIGHT YEARS OF SOME OF THE BRIGHTEST STARS

Name of Star	Constellation in which Found	Approximate Distance from Earth
Altair	Aquila	16
Antares	Scorpius	70
Arcturus	Boötes	36
Betelguese	Orion	600
Polaris	Ursa Minor	400
Procyon	Canis Minor	11
Regulus	Leo	67
Sirius	Canis Major	9
Spica	Virgo	155
Vega	Lyra	27

Table 23.2

HOW OUR SUN COMPARES WITH SOME OF THE OTHER STARS IN COLOR, TEMPERATURE, SIZE, AND AGE

Name of Star	Color and Size	Approximate Temperature (°F)	Approximate Size Compared with Our Sun		Comparative Age
			Larger (X)	Smaller (X)	
Betelguese[*]	Red supergiant	5,000	X		Youth
Antares[†]	Orange supergiant	6,000	X		Youth
Arcturus[‡]	Orange giant	7,500	X		Youth
Capella	Yellow giant	10,000	X		Youth
Deneb	Blue giant	16,000	X		Youth
Rigel	Blue-white subgiant	100,000	X		Youth
Sirius	Blue dwarf	16,000	X		Youth
Sun	Yellow dwarf	10,000			Middle age
Companion Star of Sirius	Orange subdwarf	6,000		X	Middle age
Krueger 60B (visible only with telescope)	Red subdwarf	5,000		X	Old age

[*] Diameter 250 times larger than that of Sun.
[†] Diameter 450 times larger than that of Sun.
[‡] Diameter 30 times larger than that of Sun.

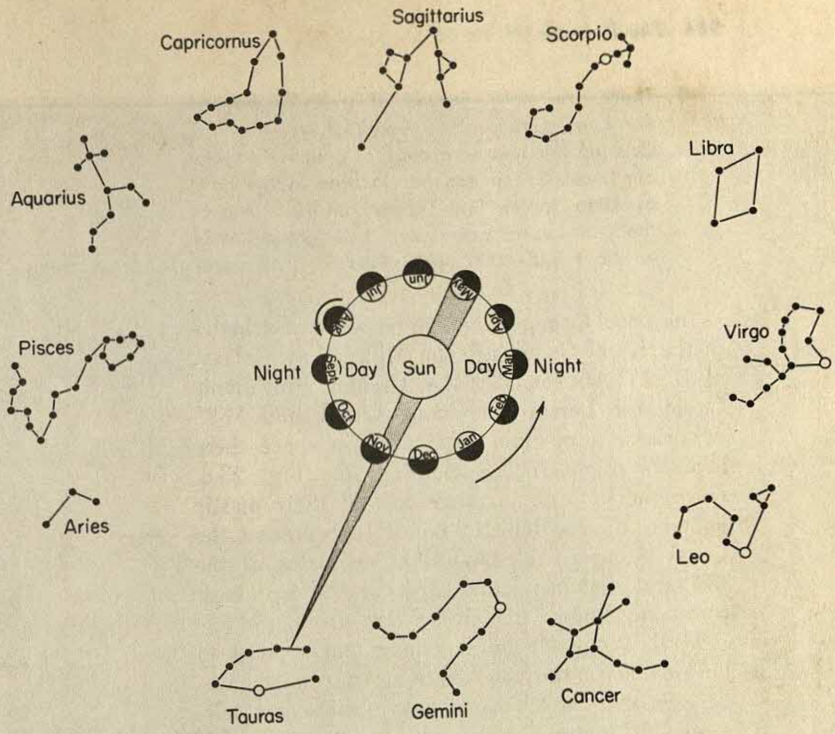


Fig. 23.1 Signs of the Zodiac. The earth's revolution around the sun makes it possible for us to see different constellations at different seasons.

2. What is the Milky Way?

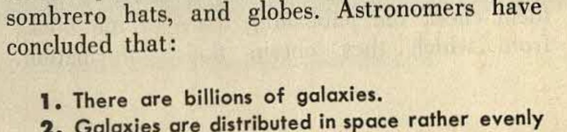
Our sun is one star in a vast system of more than 100 billion stars called the Milky Way Galaxy, or the Galaxy. Astronomers think that this galaxy, composed of stars, clouds, dust, and gas, is shaped like a giant lens with spiral arms. They estimate that it is 100,000 light years in diameter and 10,000 light years thick, and that our solar system is located 20,000 light years from its center. See Fig. 23.2. Because our solar system is inside this galaxy, astronomers can take photographs of only that part of it which can be seen from the inside looking out. To photograph the whole galaxy, astronomers would have to be outside of the galaxy looking at it from deep space. The most spectacular part of the galaxy as seen from the inside is the *Milky Way*, a hazy, white, cloudy band stretching across the evening sky. This visible band is composed of those stars in the galaxy which an observer sees as he looks out through the rim of the galaxy along its 100,000-light-year diameter.

3. What is beyond the Milky Way Galaxy?

During their reading about the Milky Way Galaxy (see Fig. 23.2), the children may have seen photographs of other galaxies and have discovered that galaxies may have many shapes. About 80 per cent of them are either open or closed spirals. Others are shaped like clouds, sombrero hats, and globes. Astronomers have concluded that:

1. There are billions of galaxies.
2. Galaxies are distributed in space rather evenly and, on an average, 2 million light years apart.
3. There are galaxies as distant in space as 2 billion light years which is the maximum distance in space that the 200-inch telescope on Mount Palomar can penetrate.
4. Other galaxies may exist at much greater distances than 2 billion light years.
5. The average diameter of a galaxy is between 10,000 and 15,000 light years.
6. Galaxies form systems or groups of galaxies that revolve about a central point.
7. Our galaxy belongs to a group of galaxies known as the *Local Group*.

Fig. 23.2 Side view of our galaxy.



8. There are many groups of galaxies beyond our Local Group. (See Fig. 23.3.)

9. One of the nearer groups of galaxies beyond our Local Group can be located in the bowl of Ursa Major (Big Dipper). M-81 is one of the best-known galaxies in this group. M-81 is about 8,000,000 light years from the earth.

The Local Group. The five best-known galaxies in the Local Group are the Milky Way Galaxy, M-31 in Andromeda, the Greater Magellanic Cloud, the Lesser Magellanic Cloud, and M-33 in Triangulum. Seen from deep in space these galaxies might look something like Fig. 23.3. Have the children arrange five of their plastic galaxies on the bulletin board to represent the Local Group. Table 23.3 lists estimates of the size and distance from earth of the five most commonly known galaxies in this group.

M-31, the great spiral galaxy that appears to be located in the constellation Andromeda, can be seen without a pair of field glasses or a telescope. It looks like a tiny, hazy cloud. This galaxy is frequently called our galaxy's twin because it is about the same size and seems to be about the same shape (see Fig. 23.4).

When the children are looking for information about the sizes and distances of galaxies, have them check the publishing dates of the books from which they obtain their information. Remind them that these figures are only estimates and that, as astronomers improve their techniques and gather new information, these estimates may change.

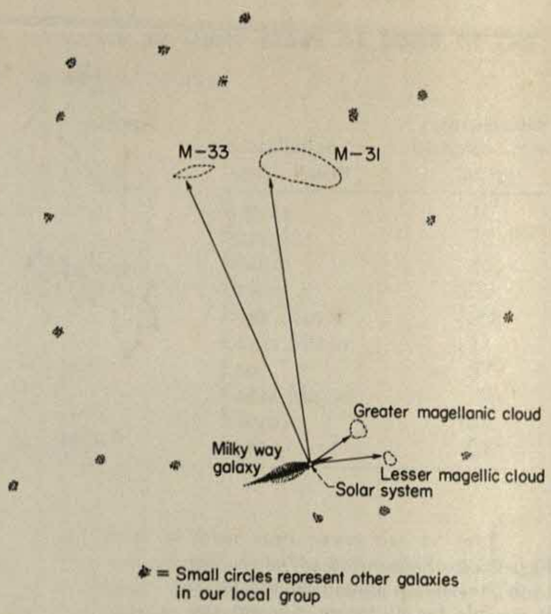


Fig. 23.3 Our galaxy belongs to a cluster of galaxies called the "Local Group." The galaxies revolve around a common center.

Table 23.3

THE ESTIMATED DIAMETERS OF FIVE OF THE GALAXIES IN THE LOCAL GROUP AND THEIR DISTANCES FROM THE EARTH

Name	Constellation in which Located	Estimated Diameter (in Light years)	Estimated Distance from Earth (in Light years)
The Galaxy (Milky Way Galaxy)	—	100,000	—
M-31 (Visible without field glasses)	Andromeda	120,000	1,500,000,000
M-33 (Visible with telescope)	Triangulum	? (smaller than Milky Way Galaxy)	1,500,000,000
Greater Magellanic Cloud (Not visible in Northern Hemisphere)	—	30,000	150,000
Lesser Magellanic Cloud (Not visible in Northern Hemisphere)	—	20,000	168,000

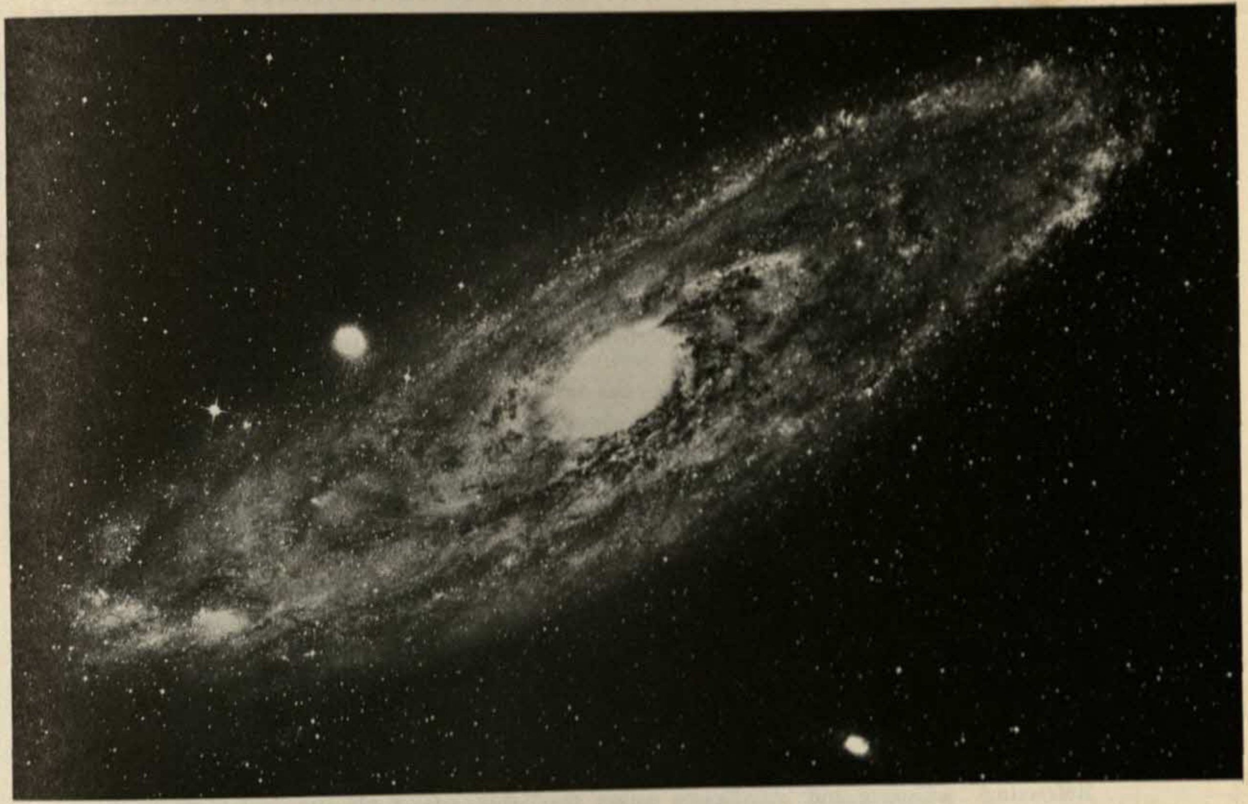
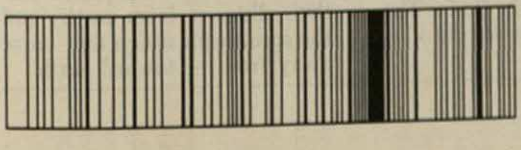


Fig. 23.4 M-31, a spiral galaxy, can be seen in the constellation Andromeda. *Courtesy Lick Observatory.*

During their reading periods some of the children may have learned that the galaxies in our universe may be moving away from our Local Group with great speeds, causing the universe to expand. Suggest to those pupils who wish to probe more deeply into the theory of the expanding universe that they read about these things:

Fig. 23.5 Part of the spectrum of a star. Astronomers have learned to identify the chemical composition of a star by studying the bright and dark lines in its spectrum. Astronomers can also estimate a star's temperature, size, distance, speed, and the direction in which it is moving (away from or toward the earth) by studying these bright and dark lines. Similar information can be obtained by studying the spectra of galaxies.



1. What evidence is there that the universe is constantly changing?
2. What proof do astronomers have that the universe is expanding in all directions? How do they know that galaxies are receding from each other? (See Fig. 23.5 and Table 23.4.)
3. Why are all the heavenly bodies, including galaxies, really not where astronomers see them?
4. What deductions do scientists make from the evidence that the earth is about five billion years old? (The oldest stars are about five billion years old and the recession of the galaxies began about five billion years ago.)
5. How do the theories of Abbé Le Maître and Dr. George Gamow explain the expanding universe?
6. What are the theories about the shape of the universe?

4. What are some of the instruments astronomers use to increase their "seeing power"?

Table 23.4

SOME INSTRUMENTS ASTRONOMERS USE TO INCREASE THEIR "SEEING POWER" AND SOME OF THE THINGS THEY FIND OUT BY USING THEM

Name of Instrument	With What Instrument Used	How It Operates	What It Is Used for
Camera	Telescopes and spectroscopes	Collects light on photographic film	To take pictures of planets, satellites, comets, and the light from stars and galaxies
Photoelectric cell	Telescopes and spectroscopes	A light-sensitive material in the cell (eye) releases electrons when light shines on it and converts the light energy into electricity	To investigate the brightness and temperature of the sun, moon, planets, and stars; it measures differences in brightness more precisely than photographic film
Radar (radio telescope)	Telescopes and spectroscopes	Consists of two parabolic (concave) antennas shaped like concave mirrors, which are connected to short-wave receiving sets; these antennas collect invisible light rays. (One of the larger instruments is located in Jodrell Banks, England)	To bounce light (invisible) rays off such bodies as the moon; to count meteors in our atmosphere; to study cosmic dust and gases in space; to locate invisible cosmic clouds and other objects in space
Refracting telescope	Camera and spectroscope	Lenses collect the light (refract or bend it) and direct the light into the lens in the objective which magnifies it	Its uses are similar to the reflecting telescope, but its field is more limited. (The largest refracting telescope (40″ lens) is located in Yerkes Observatory, Williams Bay, Wis.)
Reflecting telescope	Camera and spectroscope	Light is collected on a concave mirror and magnified by the objective lens (eyepiece). The Mt. Palomar 200-inch telescope in California gathers 360,000 times as much light as the human eye and can "see" two billion light years into space	To photograph the members of our solar system, the light from distant stars, and the light from remote galaxies; can penetrate into space farther than the largest refracting telescope
Spectroscope	Telescope, photoelectric cell and camera	A prism, or diffraction grating, in the instrument separates the light passed through it into its spectral colors. (The presence of each different kind of element in an object that gives off light can be identified by its spectrum. See Fig. 23.5, The Electromagnetic Spectrum.)	To investigate the composition of the sun and the stars; the composition and amount of the atmosphere of the planets; the size and weight of stars; the speed of rotation and revolution of stars and galaxies and their distance from earth; and the speed with which they move away from or toward earth

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Our sun is a star. Stars are suns. All stars, except our sun, are beyond the solar system. Some stars are hotter and some are cooler than our sun. Constellations are useful in helping us locate some of the brighter stars. We do not really see the stars; we see the starlight coming from them.

Distances to the stars are so great that astronomers measure star distances in light years. All the light which we see coming from the stars, except for that from our own sun star, has been traveling earthward for four years or more. Atmosphere and distance cause the stars to twinkle and seem to have points.

Stars are all around the earth. The earth's rotation causes some of the stars to appear to rise in the east and set in the west. The stars above the pole of the earth do not rise and set but can be seen all night long. Some stars can be seen in only one hemisphere. Stars shine all the time. Through the earth's atmosphere, stars cannot be seen in the daytime because their light cannot be seen through the very bright light of the sun. The earth's revolution causes the changes we see in the constellations in the evening sky during the different seasons and months of the year.

2. The Milky Way, seen in the evening sky, is a part of the Milky Way Galaxy. This galaxy is a vast system of more than 100 billion stars, of which our sun is one star. Our solar system is in the Milky Way Galaxy. The stars in our galaxy revolve around a center point in the galaxy.

3. There are billions of other galaxies in the universe. Not all galaxies have the same shape. Galaxies can be seen in space as far as the largest telescope can penetrate. Galaxies form groups and rotate about a common center point. The Milky Way Galaxy belongs to a group of galaxies known as the *Local Group.* Deep in space and beyond the Local Group, there are many other groups of galaxies.

4. Astronomers use many different kinds and combinations of instruments to help them explore our universe.

Chapter Twenty-Four

Space Exploration

Missiles, Jets, and Rockets

INQUIRIES

1. What do we do when we move things? What do we use to move things?

2. What do we do when we throw something up into the air? What do we do when we lift things?

3. How do animals push and pull things?

4. How do most engines push or pull?

5. How do missile, jet, and rocket engines differ from most engines? How are they the same?

6. How does the force exerted by the engines of missiles, jets, and rockets cause them to move? Why are they called *reaction engines*?

7. How do reaction engines work?

8. How do jets, missiles, and rockets differ? Why can't jet planes fly in space?

1. What do we do when we move things? What do we use to move things?

Discuss how chairs, tables, desks, and pianos be moved. Discuss why these objects do not move by themselves. Ask the children to try moving them. What do they need to do to move them? What is needed to move things? (We move things by pushing or pulling them. We use energy to move things.)

2. What do we do when we throw something up into the air? What do we do when we lift things?

Have the children do the following things and question them about these experiences.

Practice throwing a basketball into the basket. Ask the children, "How do you get the ball up to the basket? What do you use to do this?"

Lift an empty pail. Fill the pail half full of water. Lift it. Put more water in the pail. Lift it again. Ask the children, "How do you get the pail to move up from the floor? What do you use to do this?"

3. How do animals push and pull things?

Discuss how animals move things. Collect pictures of animals moving things, and ask the children questions like these: What do animals use to push and pull their loads? What are such animals as camels and pack horses doing when they carry things on their backs?

4. How do most engines push or pull?

Have the children bring to school wind-up toys, spring toys, toy cars, trucks, and boats with electric motors in them, electric trains, and model airplanes and helicopters. If they bring either models or working models of jets, missiles, or rockets, keep these separate for a later experience. The choice of self-propelled toys is extensive.

Have the children play with each toy and try to decide which ones are pushed by their "engines." Check their observations with the following questions: Where is the force applied that causes them to move?

Have them start the toy and hold it so that they can watch its moving parts. Ask them "what part of the toy is being moved by the force of the 'engine'?"

Now tell them to operate the toy as the manufacturer intended and to watch the moving parts. Find out whether they understand the operation of the engine by asking "What are the moving parts touching? On what are they pulling or pushing?"

Discuss how real cars, trucks, trains, and planes move. Where is their force (engine)? Have the children find out what external parts are moved by the engine. On what are these moving parts pushing or pulling?

5. How do missile, jet, and rocket engines differ from most engines? How are they the same?

Let the children study pictures and models of rockets, jets, and missiles. Provide opportunities to observe the launching of toy rockets. The children should observe and reason like this: Rocket, missile, and jet engines are different from other engines because they have neither wheels nor propellers. Without these external moving parts, the force of the engine cannot be applied against anything *outside* the rocket, missile, or jet. Where, then, must these engines apply force? (To the inside of the rocket, missile, or jet.) Why can a rocket engine push the rocket through space? What does it push on in space? (The inside of the rocket.)

6. How does the force exerted by the engines of missiles, jets, and rockets cause them to move? Why are they called *reaction engines*?

Here are some simple experiments for the children to try. Give them the following directions and have them observe what happens in each experiment. Use the questions that follow to check their understanding of what happens.

Stand on a pair of roller skates. Do not fasten them to your feet. The roller skates represent your rocket. You are the force in the rocket. Jump backward off the skates. You, the force, are "jumping" out of the rocket (skates). What happens to the skates? In what direction are they pushed? Repeat by jumping forward off the skates.

Lay a piece of board on a number of marbles. Stand on it. Have someone hold your hand to steady you. Try jumping off the board. What happens? Compare the direction the board moves to the direction in which you jump. Jump off in different directions. Why can you begin to predict which way the board will move?

Stand again on your board. Have someone hold one of your hands to steady you. This time throw a ball with the other hand as hard as you can. This time the ball is the force leaving the rocket. What happens to you and to the board? In which direction does the ball go? In which direction does the board go? In which direction do you go?

Fasten a wide rubber band, sling-shot fashion, to the toe grips of roller skates. Stretch the rubber band and tie a thread from the band to the heel of the skate. Be sure to leave about one inch of thread between the rubber band and the heel of the skate. Put a ball in the rubber band the same way you would put a stone in a sling shot. Burn the thread with a match to release the energy in the stretched rubber band. What happens to the ball? What does the ball represent? What happens to the skate? What does the skate represent?

There will be many more experiments like these in your science books. Try them.

Try answering these questions. Why does a cannon recoil (jump backward) when it is fired? Why does a rifle "kick" back when it is fired? Why do people sometimes fall in the lake when they try to step ashore out of a small boat? If you could jump off a space platform, what would happen to the platform? How do the things you have seen happen in your experiments compare with what happens when a rocket is launched? Try to state in your own words what happened so that your statement will apply to everything you tried.

When scientists get the same result over and over, they call it a *law*. Have the children read about Sir Isaac Newton and his three laws of motion.

Newton's laws of motion

First Law of Motion. Every object will remain in a state of rest (motionless) unless it is acted upon by some force. Every object will continue forever at the same speed and in the same direction unless it is acted upon by some force.

Second Law of Motion. A change of motion is proportional to the force causing the change and takes place in the direction in which the force is acting. A change of momentum is proportional to the force causing the change and takes place in the increase or decrease in velocity (acceleration).

Third Law of Motion. To every *action* there is always an equal and opposite, or contrary *reaction.*

Ask the children: How do Newton's laws of motion apply to the experiences you have just completed? With how many of these laws have you had experiences? With which one did you work when you discovered that desks and chairs do not move unless some force pushes or pulls them? Compare the ways you stated what happened to the way Newton stated what will always happen. How long ago did Sir Isaac Newton live? How old was he when he stated these laws of motion? How many years ago was this?

7. How do reaction engines work?

The following experiences will help the children to understand how *reaction engines* work. Their answers to the questions will help you evaluate their understandings. The directions are for the class.

Fill a large pan with water. Fill a small glass tumbler with water by laying it in the pan of water. Invert the glass while it is still submerged in the large pan. It will remain full of water as long as the open end of the glass is below the surface of the water. Now inflate a toy balloon with air. Guess how many glassfuls of air are in the balloon. Hold the inverted glass of water just below the surface of the water in the pan with the left hand. Hold the neck of the balloon under the open end of the glass. Slowly release air from the balloon into the glass until the air has pushed all the water out of the glass. Pinch the neck of the balloon to hold the remaining air in the balloon until the glass has been refilled with water. Repeat over and over until all the air in the balloon has been measured by the glass. How many times did the air in the balloon fill the glass? Compare your guess with the actual number of glassfuls of air that were in the balloon. How can so much air be put into the balloon?

Inflate the balloon again. Hold it tightly by the neck. Now release it. What happens? Where does the air leave the balloon? In what direction does the air escape? In what direction does the balloon move? Which one of Newton's laws explains what happened in this experiment?

Draw a picture of the inflated balloon before the air is released. Use arrows inside the balloon to show what the air is doing. Draw another picture to show what the air is doing when the air is released from the balloon. Where does the action and the reaction take place?

Use a paper bag or a plastic bag as a rocket case and blow up your balloon inside the bag. The inflated balloon should fit tightly in the bag. The inflated balloon is the "engine." Release the balloon. What caused the balloon to move? Where is the force applied? Which one of Newton's laws explains what happened?

Hook two or three paper clips in a straight line from the top to the bottom of the bag. Run a long piece of nylon fishline through the paper clips. Hold the string tightly. Now, put the balloon in the bag and inflate it until it fits snugly in the bag. Release the balloon. Explain what happened. Try flying the paper bag rocket at an angle, up a stair well.

Try using three balloons in three bags to build a three-stage rocket. Tie the necks of the balloons used in the second and third stages until you are ready to "fire" them. Also fasten the bags together in a row. Hang them all horizontally on a nylon fishline with paper clips. "Fire" stage one. Measure how far it travels on the line. Drop off stage one. Untie stage two and "fire" it from the place where stage one ended its flight. "Fire" stage three. Let the children work on this three-stage effect. They may invent better ways to show two- and three-stage rockets.

Use a Pyrex bottle or flask. Stretch the neck of a balloon over the mouth of the bottle. Slowly heat the bottle of air. What happens? Where must all this air come from? What must happen to air when it is heated?

Use a Pyrex test tube. Close it tightly with a cork stopper. Hold the test tube with a test tube holder. Heat the test tube with a candle. What happens? (The cork pops out of the tube.) Why is a *reaction* not seen? (The test tube was held so it could not move.) Hang the test tube horizontally on a horizontal flight line by wires and paper clips so that it will be free to move. Put in the cork stopper and heat with the candle. Compare the result of this experiment with the previous one. (The cork and the test tube moved in opposite directions. There was a *reaction* as well as an *action.*) Measure on the flight wire how far the test tube moves.

Put a *few drops* of water in your test tube. Hang it on your flight wire. Cork and heat it. What causes the action this time? How far does the reaction move the test tube?

Put three or four paper matches in your test tube. Hang the tube on your flight wire. Insert a stopper in the tube. Apply heat to the lower side of the tube. Explain what happens. This time you have used a fuel in your reaction engine. What is the fuel? How far does the test tube move?

Florists use a little plastic tube shaped like a rocket to hold water for floral pieces. Get some of these and buy some corks to fit the open ends. Attach a string to the large end of the cork. Let the children put vinegar in the plastic rocket. Quickly add a little baking soda and cork tightly. Invert the tube and hold it in launching position by grasping the loose end of the string. What happens? What caused it?

Buy some CO_2 (carbon dioxide) cartridges and a needle-like trigger to "fire" them. Drugstores, toy stores, and novelty stores sell them. They are safe to use. The cartridges have carbon dioxide under pressure packed and sealed in them. Release the pressure by making a pin hole in the end with the needle-like trigger. A strong needle and a hammer can also be used to release the pressure. Build a rocket case from a paper towel tube. Add a paper nose cone. Make a paper ring just the size of the CO_2 cartridge and fasten it into the rear of the towel tube. This ring makes a container in which to place the CO_2 cartridge. Hang the completed rocket by paper clips on your flight string. Use a very long string. Stretch it tightly and secure both ends to trees. These rockets travel fast and may reach the end of the string while still under motion. Insert the CO_2 cartridge in the paper holder inside the rocket. Puncture the cartridge with the needle and watch the rocket fly.

The fifth grade children in Fig. 24.1 made rocket cases from solid pieces of balsa wood. Since balsa wood is soft, it is easy to work; its light weight makes it good to fly. A pocket to tightly hold the CO_2 cartridge was bored in the block of balsa wood. The outside was shaped with sandpaper. Three screw eyes, screwed into the case in a straight line, hold the rocket on the guide string. Use the CO_2 cartridges to fly these balsa wood rockets. Use a very long line. Be sure to tie both ends of the nylon fishline to trees because they fly very far and very fast. Some-

Fig. 24.1 Launching a balsa wood rocket. *Courtesy Marion E. Betar.*

times they fly as far as a city block or as high as a flag pole. These rockets are easy to make and fun to fly. Let the children make some and fly them. Measure how far they go in horizontal flight. Measure how high they fly in an angled flight.

There is no danger from any of the preceding rocket experiments. The commercial toy rockets also are safe to fly. As long as the action does not include fire or explosive chemicals, the children can learn how rocket engines produce an action. This is a good time to explain that real rockets burn dangerous fuels to produce their great push, *thrust.* Discuss why, at the launching countdown, everyone goes inside a concrete shelter. Discuss why students should not experiment with fuels in rockets.

Look up the history of jet propulsion. Read about the squid, the jet-propelled fish. Read how the Chinese used rockets long ago. Read about Robert H. Goddard, the American who is called the *father of rockets.* Read about the V-2 rockets developed by the Germans in World War II. Read about Wernher von Braun and his contributions in this field.

8. How do jets, missiles, and rockets differ? Why can't jet planes fly in space?

Discuss this problem. Look at pictures of jets, missiles, and rockets and read about each. Go to an airport where jet planes can be seen. Watch jets, missiles, and rockets in flight on television. Study movies of jets, missiles, and rockets in flight.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. We move things by pushing or pulling them.
2. Throwing is pushing and lifting is pulling. Force is needed to push or pull things. Gravity pulls things to the earth.
3. Animals push and pull things.
4. Most engines use force to cause some part of the machine to push or pull on something that touches the outside of the machine, like the air, water, or earth.
5. Jet, missile, and rocket engines are different from most engines. They have

no wheels or propellers to push on the air. Rocket engines can even fly where there is no air. These engines are different because they push on the insides of themselves and not on something outside which touches them.

6. When a force leaves an object in one direction, the object is pushed by this force in the opposite direction. Newton's third law says that for every action there is an equal and opposite reaction.

7. The engines in jets, missiles, and rockets are called *reaction engines* because they react with a forward motion which is opposite in direction to the force of the action caused by the hot gas rushing out of them.

8. The reaction is called *thrust*. Reaction engines are also called *jet engines.* There are two kinds of jet engines. A rocket jet carries its own supply of fuel and oxygen. An atmospheric jet carries only fuel and obtains the oxygen it needs for burning from the air.

Chapter Twenty-Five

Orbiting Satellites

INQUIRIES

1. What is a satellite? What is an orbit?

2. What do scientists hope to learn by sending rockets and satellites into space? How does man benefit from the space program?

3. What is used to put man-made satellites into orbit?

4. Why does it take so much thrust to put a satellite into orbit?

5. How far beyond the earth does air resistance extend? How far beyond the earth does the earth's gravitational field extend?

6. What keeps a satellite moving after the rocket engines burn out?

7. What makes an orbiting satellite follow a curved path? Why is the orbit a closed curve? Why is a permanent circular orbit more difficult to achieve?

8. Why do satellites commonly orbit in a closed curved path called an *ellipse*?

9. Why do satellites not pass over the same part of the world on each trip? Why cannot all satellites be seen? Why can some satellites be seen only just before sunrise or just after sunset? How do we know they pass over if they cannot be seen?

10. How can the moon be reached by rockets or satellites? How can they be made to orbit the moon?

1. What is a satellite? What is an orbit?

Have the children look in the dictionary and in encylopedias for information about satellites and orbits and check their readings with questions like the following:

Why is the moon a natural satellite? Around what does it orbit? Why is our earth a satellite? Around what does it orbit? Why are planets and comets satellites?

How are the orbits of *man-made* satellites like the orbits of *natural* satellites?

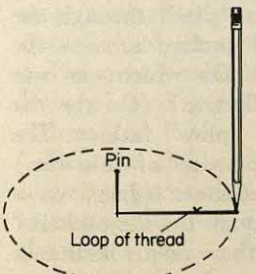
By reading, the class should discover that the normal shape of natural and man-made satellite orbits is an ellipse and not a circle. The pupils need to look up the meaning of the word *ellipse.* Have them notice that both a circle and an ellipse are closed curves and that an object following either returns to its starting point.

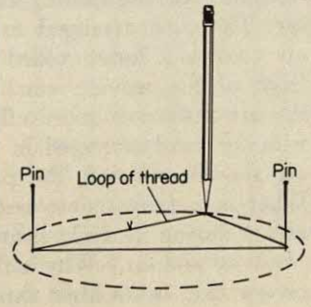
Here are simple directions to give the children for drawing both a circle and an ellipse. Double a piece of thread and tie a knot two inches from the end of the loop. Stick a pin in a pad of notebook paper. Slip the loop over the pin and hold the thread close to the paper. Put the pencil point in the far end of the loop. Hold the loop tightly with the pencil and draw a circle (see Figs. 25.1 and 25.2).

To draw an ellipse, stick *two* pins in the pad of notebook paper. The pins should be a little less than two inches apart. Put the two-inch loop of thread around both pins. Now put the pencil point inside the loop and draw around the two pins, always keeping the thread tight and using the loop of thread as a guide for the pencil. Describe how this shape is different from a circle. Both the circle and ellipse are closed curved lines that always come back to the starting point. An ellipse is sometimes described as an elongated circle. A circle curves around *one point* and an ellipse curves around *two points.*

Fig. 25.1 (*left*) How to draw a circle (see text). A circle curves around one point.

Fig. 25.2 (*right*) How to draw an ellipse (see text). An ellipse curves around two points.





Draw a series of ellipses with the two-inch loop. Each time move the two pins closer together. Observe the change in each new ellipse. What does it look more and more like? Finally, put the *two pins in one hole.* What do you draw when the two points become one point? (A circle.)

Another method that can be used for learning to see that an ellipse is a sort of elongated circle is laying a loop of thread in a circle and then pulling outward on any two opposing sides.

Still another way to observe how an ellipse and a circle are formed is to look down into a drinking glass that is about a third full of water. Does the water make a circle or an ellipse where it touches the inside of the glass? Now tip the glass. Look down in it again. Now does the water make a circle or an ellipse? Tip the glass more and more. Have the children watch the shape change.

In the children's first observations, the orbit of the earth and a comet may have seemed quite different. Can they tell whether the two points around which the earth's orbital ellipse curves are close together or far apart? Would the two points around which the orbital ellipse of a comet curves be close together or far apart? One of the two points represents the *center* of the object around which the satellite is orbiting.

2. What do scientists hope to learn by sending rockets and satellites into space? How does man benefit from the space program?

Have the children discuss what scientists hope to learn from man-made satellites that orbit the earth, moon, sun, and other bodies in the solar system.

Discuss some of the instruments used in unmanned rockets and satellites to send scientific facts back to earth. How many of the following questions can the children answer? What kinds of information are spacecraft programmed to collect? Why are animals and men sent into space? How are capsules and their cargoes recovered from sea, land, and air? Why can telescopes get better pictures of the heavens from a satellite?

Discuss how satellites in earth orbit are being used to predict the weather. Also discuss how satellites aid navigation and worldwide communication. Ask the class to make predictions about the future roles of man-made satellites and spacecraft.

Make a chart for the classroom with the title, "What We Think Scientists Want To Learn from Satellites and Spacecraft." On it list questions which the class thinks can be answered by information obtained from detecting instruments carried by satellites. Have them watch news sources for scientific information gathered by satellites.

Make another chart with the title, "How the Space Program Is Already Benefiting Mankind." Clip to this chart all news items concerning such benefits. Be sure the pupils include items which credit the space program for the *miniaturization* of so many things we use, for progress in meteorology, medicine, communication, and so on. Pupils should realize that there is "constant fallout" of knowledge and technology *to them* from the space program.

3. What is used to put man-made satellites into orbit?

Have the children look up data about several man-made satellites. During the discussion of their readings, have them compare the size, shape, and weight of each satellite with the size of the rockets and number of rocket stages needed to put it into orbit.

4. Why does it take so much thrust to put a satellite into orbit?

As the children do these experiments, check their understandings with questions similar to those included in the directions that follow.

Let a rubber ball represent a satellite. Throw the rubber ball up into the air as high as possible. All the children can try throwing the ball up into the air. Who can throw it highest? Why can some throw it higher? Why can the ball not be made to orbit the earth?

Put the end of a three-foot rubber cord through a small rubber ball and tie the rubber cord securely to the ball. Have someone hold the free end of the rubber cord on the ground. Have another child throw this ball up into the air as high as he can. See the rubber cord pull (drag) it back to the earth. The rubber ball represents the satellite the child is trying to *thrust* into orbit; the stretched rubber cord represents a force that pulls (drags) the ball back to the earth. When the ball was thrown without the rubber cord, what force pulled (dragged) it back? (Gravity.)

Buy or borrow a small toy automobile. Attach a square card across the front of the car so that it looks like a snowplow blade. This card should not touch the "ground" under the car. Build an artificial hill, using a stack of books and a board or cardboard ramp. Place the car at the top of the incline and release (not push) it. Measure the distance between its starting and finishing points. Repeat this at least ten times and average the ten recorded distances it travels.

Remove the card and turn it so that the leading edge of the card looks as if it would "slice" through the air when the car moves forward. Again start the car at the top of the incline and measure the distance between its starting and finishing points. Repeat this procedure the same number of times as it was repeated in the first half of this experiment. Find the average distance the car travels.

Ask the children these questions: What effect does the position of the card have on the average distance traveled by the car? Which car goes farther? (The one with the card in a position to "slice" through the air should have a greater average distance of travel. The one with the card in a position to "plow" through the air should have a smaller average distance of travel. This card creates a greater added surface area to the front of the car to face the normal air resistance on the leading surface of the moving car. The card arranged to "slice" through the air creates a lesser added surface area to the front of the moving car.) On which car was the air resistance more effective? (On the car with the card arranged in "plow" fashion. The air slowed, resisted, the passage of this car.) What two things cause resistance (drag) on a rocket during its flight through the atmosphere? (Gravity and air.) Why is there no air resistance on a rocket in its flight through space?

5. How far beyond the earth does air resistance extend? How far beyond the earth does the earth's gravitational field extend?

The earth's diameter is about 8000 miles. Have the children use their skill with a pin, a thread, and a pencil to draw a circle on lined notebook paper. The diameter of the circle should cover eight spaces on their notebook paper. Ask them how many miles each space represents?

The earth's atmosphere surrounds the earth like an air blanket. Most of the air is relatively close to the earth. Beyond an altitude of 200 miles, the molecules and atoms of matter are so widely scattered that they offer very little resistance. The children have allowed one space on their notebook paper to represent 1000 miles. Ask them to figure how to represent 200 miles on their paper. A centimeter ruler will help them to make a better approximation of this distance. Now have them draw another circle around their earth to approximate the 200 miles of air resistance. This layer of atmosphere can be colored light blue. Compared to the size of the earth, this air blanket is very thin. It is this layer of air and its resistance that rockets must "plow" through to reach orbital distance.

Draw a series of increasingly larger circles around the earth. See whether the class can guess what force these circles represent. Ask them how far these circles should extend. (See Chap. 20, Inquiries 8 and 9.)

Look up the average distance from the earth to the moon. Remember that, in the model being constructed, one space on the notebook paper equals 1000 miles. Figure the number of spaces needed between their model of the earth and a model of the moon. Have a group of children paste together the number of pieces of notebook paper needed to represent the moon's distance.

Have another group look up the size of the moon's diameter and draw a moon, using the same scale of one space for each 1000 miles.

The moon's orbit around the earth is an ellipse. Have a third group of children find what its nearest and farthest distances are in miles.

Help the children recall that Newton's law of universal gravitation says that *there is a mutual attraction between all bodies.* This means that the moon has a gravitational field too. Draw gravity circles around the moon. The earth's gravitational field extends all the way to the moon and beyond. Draw the gravity circles of each. The gravity circles of the earth should extend beyond the moon. The gravity circles of the moon should go beyond the earth. (See Chap. 20, Inquiries 7 and 8.) The effect of the earth's gravity decreases with distance from the earth. The moon's gravity decreases with distance, too. The earth has more gravity than the moon because it has more mass. Between the moon and the earth, there is a place where the moon's gravity and the earth's gravity are equally weak. This place is about 23,600 miles from the moon. Have the children find this place on their notebook paper and indicate that this is the place where the gravitational pull of the moon equals the gravitational pull of the earth. Between this point and the moon, the moon's gravity is stronger and between this point and the earth, the earth's gravity is stronger.

6. What keeps a satellite moving after the rocket engines burn out?

Direct the children in the following experiences, and evaluate their understandings with questions similar to the ones suggested.

Bring roller skates to school. Go to the gymnasium or to some paved area. Skate until you have worked up speed. Stop putting force on the skates and see how far you can roll on them. Measure how far you roll. Try rolling on the skates after you have achieved different speeds. When do you roll farther? What causes you to stop rolling?

Bring a bicycle to school. Try accelerating the bicycle to different speeds and then letting it roll to a stop. How far does the bicycle roll each time? When does it roll farther? What causes it to stop? The distance of free roll on skates or on a bicycle is called the *force of momentum*, or *momentum*.

Arrange a large sheet of oak tag or stiff cardboard to form a valley and the sides of the hills on either side of the valley. Roll a toy car down one hill. What happens as it nears the bottom of the hill? (It gains speed.) What causes it to gain speed? (Gravity and the force of momentum.) What would happen if the hill were longer? (The car would gain more speed.) Find out whether any student has ever been in, or on, moving vehicles, such as sleds, bicycles, skis, or automobiles, when they rolled or slid down one hill and up another. When did these vehicles gain momentum and when did they lose momentum? When did gravity cause them to gain momentum? When did gravity cause them to lose momentum?

Have the children use the picture of the earth and its air blanket which they made for the previous inquiry. On it draw a flight path for a three-stage rocket (carrying a satellite), which is being launched directly *away from* the earth. If its last rocket motor burns out after it has left the earth's atmosphere, why will it not keep moving at its final speed on its momentum?

Review Newton's first law of motion in Inquiry 6 of Chap. 24. The second part of this first law states that *an object will continue forever at the same speed and in the same direction unless it is acted upon by some force.* Discuss whether a satellite will keep moving on its momentum "forever at the same speed." What "force is acting on it" to cause it to lose momentum? (The force of gravity.) What effect does distance from the earth have upon the loss of momentum? (The loss is reduced.) Why? (Because the effect of the earth's gravitational attraction decreases as the distance increases.)

Newton's second law states that a *change in momentum is proportional to the force causing the change and takes place in the increase or decrease in velocity (acceleration).* The satellite has experienced a *change* (decrease) *in momentum proportional* to the force of the earth's decreasing gravity. At about 200 miles, gravity decreases an object's momentum about 29 feet per second for each second it travels. Farther from the earth, as gravity decreases, the satellite's momentum is decreased by 28 feet per second for each second it travels. Farther and farther from the earth, the loss in feet per second grows less and less.

If and when all the momentum it started with is lost, the satellite will change its "direction." It will start falling back to earth. Gravity will "change (increase) its momentum" in a reverse sequence of feet per second for each second of fall until the satellite regains its original momentum.

One of the earliest moon probes, on October 11, 1958, carried the satellite "Pioneer" to 77,750 miles before gravity caused it to lose momentum, reverse its direction, and return to earth.

If even a little of the initial momentum is left, the satellite will continue to move away from the earth even though it travels only a few miles or feet per hour. Scientists had hoped that "Pioneer" would maintain enough of its momentum to cross that point 23,600 miles from the moon, where the earth's and moon's gravity are equally weak. If it could have done this, its momentum from this point on would have been increased by the moon's gravity. It would have started falling toward the moon.

Find out what a satellite's momentum must be, when it starts its flight, if it is to escape the earth's gravity or orbit around the moon or the planets. This momentum is called the *velocity of escape*. The term *velocity of escape* defines the momentum needed by an object to move away from the earth's gravity. This momentum must always be greater than the earth's attraction.

Have the pupils find out about some of the successful, unmanned moon probes and the probes of Venus and Mars. The most recent information should be obtained from NASA. See Chap. 5 for the address. NASA has many educational materials which it will send on request.

7. What makes an orbiting satellite follow a curved path? Why is the orbit a closed curve? Why is a permanent circular orbit more difficult to achieve?

Have the children do the following experiments and test their understandings with questions like the ones listed.

Gently roll a ball off the top step of a stairway. As it falls, which step does it *first* touch? Repeat this four or five times. Each time, increase the force used to push it off the top step. What causes the ball to fall on a different step each time? (The difference in its momentum.) If the force is increased, why does the ball go farther forward before it begins to fall? Describe the shape of the path of the moving ball. What makes it fall?

Take the rubber ball with the rubber cord attached to it out on the playground or into the gymnasium. Hold tightly to the rubber cord and swing the ball around above your head. Describe the flight path of the ball. Its orbit is a closed curve. Is the orbit a circle or an ellipse? Around how many points is the ball orbiting? What prevents the ball from flying out of its orbit? (The cord.) What does the cord represent? (The earth's gravity.) Swing the ball again and release the cord. What happens? Observe whether the ball continues to follow a curved path or whether it follows a straight path from the point on its orbit where it was when released. Try releasing the cord as the ball swings along different parts of its orbit and describe what happens.

Borrow a toy automobile with an electric motor. Cut about two yards of string. Tie the ends together to make a loop. Tie the knotted end of the loop to the *side* of the automobile. Hold a pencil on the floor, eraser end downward, so the pencil will serve as the center point. Put the loop over the pencil. Start the toy and put it on the floor. Describe the shape of the automobile's orbit. Start the toy again and, while it is orbiting on the floor, remove the pencil. What happens? Remove the pencil when the automobile is in different places in its orbit. Compare the results.

Draw a circular orbit and then draw a straight line with a ruler so that it just touches one point on the outside of the circle. Imagine that the ball or satellite is on this circular orbit and that, when it reaches the point where the line touches the circle, the pull of gravity is gone. Will the satellite follow the circle or the straight line? Draw more lines touching the circle at other points. Show where the satellite would go if gravity suddenly disappeared at any of these points. Show this again with the ball and rubber cord and also with the toy automobile. At every single point on the circular orbit (and there are countless points on a circle), the satellite is traveling in a straight-line direction.

Remember the second part of Newton's first law of motion which states that an object will continue forever at the same speed and *in the same direction unless it is acted upon by some force*. The *direction* of the satellite's flight (at each point on the circular orbit) is a straight line. It does not *continue* this straight-line direction because the force of gravity *acts* upon it to *change its direction* into a curve. If the force of gravity is equal to the force with which the satellite tends to leave the orbit, we can think of gravity expending its force to change the direction from a straight line to a curve. Under this condition, gravity could not change the satellite's speed. Such a condition is called 0 *gravity*. (See Chap. 20, Inquiry 10.) A man riding in such a satellite would be weightless. At 0 gravity, a satellite would continue forever at the same momentum and in the same curve if its orbit is beyond air resistance. But if any part of the orbit passes through the atmosphere, then the resistance force of the air will act upon it to change its momentum.

If a satellite travels in a curved path around a point and is always at an equal distance from the point (determined by the balance of gravity pulling it in and the force at which it tends to leave), it must close the curve at the point where it began to orbit.

Probably a permanent satellite in a circular orbit that is completely beyond the earth's atmosphere is the perfect orbit, but it is hardest to achieve because so many things must be exactly right at *exactly* the same time. At the *exact* moment a satellite goes into orbit (the time when the last rocket burns out), it must:

1. Be *completely* beyond the resistance of the earth's atmosphere.
2. Have been steered into a curved path *exactly* parallel to the curvature of the earth.
3. Be going at a momentum whose force for leaving the orbit *exactly* equals the gravitational force pulling it back to earth.

8. Why do satellites commonly orbit in a closed curved path called an *ellipse*?

The children can see an object orbiting in an ellipse if they are given these directions. Take a new pencil and stick into it two corsage pins at right angles and about two inches apart. Tie a string into a loop so that it is just a little longer than the distance between the pins. Before the knot is tied, put the string through a finger ring. Hang the ring and loop over the two pins. With a little practice, the children can hold the pencil upright and orbit the ring around the pins. An up-and-down motion of the pencil combined with a circular motion is needed. When the ring is orbiting, the ellipse can be seen. (See Fig. 25.3.)

Another way for the class to see an object traveling in an ellipse is to use the same toy automobile tied to the same loop of string that

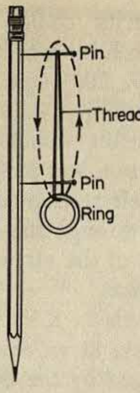


Fig. 25.3 How to orbit a ring in an ellipse.

they used in the previous inquiry. This time have them hold two pencils on the floor at a distance almost equal to the length of the loop. Next, start the automobile and watch it orbit the pencils in an ellipse. Finally, move the pencils closer together. See the ellipse and the orbit change.

The construction of a three-dimensional model of the earth and the elliptical orbit of a satellite will help children to visualize the relative sizes of each. It will also help them to visualize the path the satellite follows in relation to the earth and help them to answer many of their questions. In the construction of this model, you will have excellent opportunities for the children to use mathematical formulas and to see their applications to a problem of this nature.

The construction materials are readily obtainable and inexpensive. You will need a round rubber balloon, some string, construction paper, paper toweling, newspapers, wallpaper paste, and poster paints. Let the children help plan the construction of the model and collect the necessary materials for making it. The model described is based on the scale of 1 inch = 1000 miles. The diameter of their earth model should be 8 inches.

Give them the following directions and question them, as suggested, during the process of the construction. If you use the scale 1 inch= 1000 miles, what should be the diameter of your earth model? If you use a balloon for the form around which to build your model, to what diameter should you blow it? How are you going to know when the balloon has attained a diameter of 8 inches? (A simple way is to stand two books 8 inches apart and to test the inflated balloon's diameter between them.)

There is a mathematical formula for finding the circumference if you know the diameter. This formula is $C=\pi d$. C means circumference. The symbol π represents the number 3.1416 and d stands for diameter.

To mathematicians the formula $C=\pi d$ means that the circumference $(C)=3.1416$ multiplied by the diameter (d). If you multiply π by the diameter (d) of the earth, do you have the correct mileage for the earth's circumference? ($C = 3.1416 \times 8000$ miles.) If you want your model to have an 8-inch diameter, you can find the circumference for it with the same formula. ($C=3.1416\times 8$ inches.)

Cut a 25-inch string to represent the circumference of the earth model. Since paper and paste are to be added to the outside of the balloon, a little air should be removed so that the balloon's circumference is a little less than 25 inches. Tie the neck of the balloon securely to prevent any air from escaping. Tear newspapers into strips about two inches wide. Do not cut the newspapers. Mix some wallpaper paste according to the directions on the bag. Use your hands to spread the paste on the strips of newspaper. Wrap these around the balloon until all but the neck is covered. Apply five or six thicknesses of pasted newspaper strips before you stop. Hang the balloon by the neck until is very dry. Do not lay it down to dry or it will have a flat place on it. When it is dry, tear some 2-inch strips of paper toweling. Paste and apply one layer of these strips over the newspaper strips. Hang to dry a second time. This will make a sturdy, lightweight globe with a diameter of approximately 25 inches. Let the neck of the balloon represent the North Pole of the earth. Put the string around the globe where the equator should be and using the string as a guide, draw an equator on your globe. Look at a real globe and draw continents on your globe. Be sure the Florida peninsula shows because some of our satellites are launched from Cape Kennedy in Florida. Paint the continents and oceans on your globe.

Get a large sheet of one-inch ruled paper. Many schools use a paper like this in the primary grades for experience reading charts. If your school has this paper, use it; if not, get wrapping paper and draw the lines on it. With your pin, string, and pencil, draw first a circle with an 8-inch diameter.

Have the pupils draw the elliptical orbit of Explorer IV. This United States satellite was launched from Cape Kennedy in 1958. Scientists had hoped that Explorer IV would orbit the moon, but the satellite failed to orbit the moon. This early satellite was a cylinder 80 inches long and 6 inches in diameter; it weighed 38.43 pounds. It carried instruments and had a predicted life span of four years. Its orbital time was 111 minutes. Its minimum altitude was 180 miles and its maximum altitude 1700 miles.

This means that one end of the ellipse will be 180 miles from the earth and the other end 1700 miles from the earth. Draw a straight-line across your 8-inch circle through its center point. At the left of your circle, mark where 180 miles would be; at the right of your circle, mark where 1700 miles would be. If you put a second pin 1½ spaces to the right of the pin in the center of your circle and tie a string loop to reach from the second pin to the 180-mile distance, you can use your two pins, your loop, and your pencil to draw an ellipse. It should pass very close to your 180 and 1700 mile marks.

Now draw a second circle around the outside of your 8-inch circle to represent 200 or 250 miles of atmosphere. Color this thickness of air a light blue. Because 250 miles is one-fourth of 1000 miles, you can use ¼ inch for the atmosphere. See how the satellite at its minimum altitude of 180 miles cuts through the atmosphere. What will this do to the satellite? Paste this whole drawing on stiff cardboard.

Now cut out the center which represents the earth. Also, cut around the outside *following whichever line is the outside line.* This should slip over your globe like a collar or like the rings of Saturn.

Because many of the United States satellites are launched from Cape Kennedy in a southeasterly direction, and return to this area from a northwesterly direction, move the satellite orbit until the orbit shows this direction of flight. The 180-mile altitude should be over the ocean southeast of Florida at about the place the third-stage rocket burns out. The burn-out point is the point at which the satellite goes into orbit. You now have a fairly accurate and proportional three-dimensional model of the orbit of Explorer IV.

Draw a tiny picture of Explorer IV and put it on one end of a paper clip. Call attention to the discrepancy in size between the satellite model and the 8-inch globe. Discuss why the correct size could not be used. (The satellite would be invisible.)

Use your model to show how the satellite was launched southeast from Cape Kennedy over the ocean. Show where it went into orbit when its last stage burned out. This is where the orbit is 180 miles from the earth. Discuss why it is launched in a southeasterly direction. Discuss why it is launched over the ocean. Why are satellites not launched from the West Coast over the Pacific Ocean in a westerly direction? How much free momentum does the satellite gain if it is launched in the same direction that the earth is turning? From what geographical location on the earth would it gain the most momentum? Why?

Clip the satellite to the edge of the orbit at the 180-mile point. Slide the satellite around the orbit and observe what happens. How often does it enter the earth's atmosphere? What happens to it each time it moves through the atmosphere? How long does it take it to make one revolution? In what direction is it going? Why has it not left the earth's gravity?

Help the children to observe and make the following statements about what the satellite was doing in the *first half* of its orbit.

1. It was leaving the earth.
2. Gravity was working against the satellite.
3. Gravity was slowing it down.
4. It was not traveling at a constant speed.
5. It was losing momentum.
6. Gravity was curving its flight path.

Children should make comparable statements about what the satellite was doing in the second half of its orbit. At what point in the elliptical orbit did the satellite's momentum start to increase? At the point where the satellite reentered the atmosphere, was its momentum as great as when it left the atmosphere? (It regained the momentum it lost.) What happened to its momentum when it grazed through a section of the atmosphere? When did it regain this loss? (Never.) When did this satellite lose more momentum? (Each time it cut through the atmosphere.) How does this help the scientist to estimate the life span of a satellite? Why can the instruments in satellites orbiting in ellipses collect more information than those orbiting in circles? Why did scientists want the first satellites to be temporary? Why did they want them to burn up at the end of their life span?

Write to NASA requesting the following information:

1. Did Explorer IV burn up in 1962 as scientists predicted?
2. How many temporary and permanent United States satellites are now orbiting the earth?
3. How many temporary and permanent satellites belonging to foreign countries are now orbiting the earth?
4. What is the perigee (nearest point) and the apogee (farthest point) of the most recent temporary satellite to orbit the earth?
5. How many temporary United States Satellites are now orbiting the Moon, Venus and Mars?

Some pupils may wish to use the information regarding the perigee and apogee of the most recent satellite to orbit the earth and repeat the experience they had in making the model of the ellipse of Explorer IV.

9. Why do satellites not pass over the same part of the world on each trip? Why cannot all satellites be seen? Why can some satellites be seen only just before sunrise or just after sunset? How do we know they pass over if they cannot be seen?

Give the children directions and questions similar to the following to help them make these inquiries.

Rotate the homemade globe inside the satellite's orbit. How many hours does it take for one rotation? Which way does the earth rotate? How long does it take your satellite to orbit the earth once? How far will the earth rotate while the satellite is making the complete orbit? How many times will the satellite orbit in 24 hours?

Mark the homemade globe with hour lines running from the North to the South Poles. A real earth globe will show how to do this. Now rotate the globe and orbit the paper-clip satellite at the same time. Move both approximately as far as they would go in 111 minutes. Mark on the globe with the chalk the spot directly under the satellite. Move both again for 111 minutes. Over what part of the earth is the satellite now? Is it over the same place?

Mark where the children live on the globe. Turn the globe until the satellite is directly over the place where they live. Now repeat the directions in the preceding paragraph, marking where the satellite is at the end of each 111 minutes. How many trips does the satellite make before it passes over their town again?

Discuss why some satellites can be seen and why others cannot. Compare the sizes of some of the man-made satellites and their minimum and maximum altitudes from the earth.

Darken the room. Use a strong light for sunlight, such as the beam from a projector. Let it shine on the model. Use the model globe and satellite as you did before. Show that when the satellite passes over the children's town late at night the satellite would be in the earth's shadow and no sunlight could reach it and be reflected back to the earth. Also show that if the satellite passes over in the middle of the day, the sunlight would be so bright that the satellite could not be seen. Finally, show that the sun shines on the satellite for a few minutes before sunrise and a few minutes after sunset. This light can be seen because it is being reflected from the satellite to the earth. Clouds can also prevent a view of a satellite's passage.

Look up the locations of the tracking stations that have been built to track United States satellites. Locate these stations on the globe. Rotate the model globe and orbit the satellite as before. Watch how it flies over these stations. In what order does it pass over them?

Read about these stations and how they track satellites and receive the information which the satellites are gathering.

10. How can the moon be reached by rockets or satellites? How can they be made to orbit the moon?

Look at the scale drawing the class made in Inquiry 5. Observe the place where they discovered that the earth's and moon's gravity were equally weak. Encourage discussions by raising questions like these: How much initial momentum must a rocket have to reach and cross this point? Why will it not be going 25,000 miles per hour when it crosses this point? Why will just a few miles per hour be enough momentum for it to cross? What will happen to its momentum after it crosses this point? It gains momentum. It may orbit the moon, cross this point again, and return to the earth, gaining back the momentum it lost on its outward flight.

Have the class make a study of the Apollo flights. Learn how the astronauts elongated their elliptical orbit to take them to the moon, how they achieved moon orbit, and returned to an orbit which would bring them back to earth.

Use reference books to find the following information: How long it will take for a satellite to go to the moon? How long does it take for the moon to orbit the earth? How far would the moon revolve in its orbit during the time the satellite was in flight from the earth to the moon?

The following directions are for making a moon model. Use the same scale (1 inch=1000 miles) as was used to construct the 8-inch earth globe. Then cut a string, using 1 inch for each 1000 miles, to represent the distance from the earth to the moon. Hold one end of the string at the earth and put the moon model on the other end. Mark on the string with crayon the critical 23,600-mile point. Take the earth, moon, and satellite models to the gymnasium, or outdoors. Use the same scale (1 inch = 1000 miles) to determine how far the moon model would travel on its orbit during the time a satellite was in flight from the earth to the moon. Discuss and demonstrate why a satellite must be aimed ahead of the moon if the satellite and the moon are both to arrive at the same place in the moon's orbit at the same time.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. There are many natural satellites. The earth now has man-made satellites orbiting it. Ellipses are the natural orbits of both man-made and natural satellites.

2. Many facts can be learned from rockets and satellites. Man is already benefiting from space-age knowledge and technology.

3. Satellites are hurled into orbit by the thrust of multiple-stage rockets. It takes a tremendous thrust to place even a small satellite in orbit.

4. The earth's gravitational attraction and air resistance act as two drags on any object that leaves the earth. To put an object into orbit, the thrust must be great enough to carry the object to the speed and distance at which it can orbit before the two forces of gravity and air resistance can return it to earth.

5. Air resistance is effective only to about 200 miles. Gravitational attraction extends far into space and it decreases with distance. There is a place between the moon and the earth where the two gravitational attractions are equal.

6–7. All moving objects tend to keep on moving. Outside forces drag against them to stop their movement. The continued motion that results from the tendency of a moving object to overcome the resistance against it is called *momentum.* If a moving object is thrust beyond the drag of air resistance, if it is moving (falling) in a curve, and if its momentum in this path is exactly equal to the pull of gravity, it will orbit the earth forever in a closed circular path. Such a moving object must have an initial momentum of about 17,000 miles per hour, or from 4.5 to 4.6 miles per second, to orbit the earth. It must have an initial momentum of a little more than 25,000 miles per hour, or 7 miles per second, to break free of an earth orbit.

8. The final burn-out point of the last rocket is the point at which a satellite goes into orbit. Speeds of about 17,000 miles per hour at this point will cause satellites to orbit the earth. The momentum of the satellite, after the engine's cut-off, must be great enough to balance the drag of gravity. At greater speeds, the momentum will be enough greater than the pull of gravity, at any distance from the earth, to cause it to break free of the orbit. Twenty-five thousand miles per hour is given as the speed of escape.

To put a satellite into a *permanent circular* orbit is very difficult to do. All the following conditions must be achieved *at the point* where the satellite goes into orbit.

1. At this point, it must be *beyond* the drag of the earth's atmosphere.
2. At this point, it must have already been steered into a path *exactly parallel* to the curvature of the earth.
3. At this point, its momentum must equal exactly the pull of the earth's gravity.

To put a satellite into a *permanent elliptical* orbit is easier. The following conditions are necessary at the point where it goes into orbit.

1. At this point, it must be *beyond* the drag of the earth's atmosphere.
2. At this point, it must have been steered into a curved path.
3. At this point, its momentum must be greater than the pull of gravity. Its momentum must be about 17,000 miles per hour; greater momentum than this would cause it to escape.

To put a satellite into *temporary elliptical* orbit is easiest. The conditions that are necessary at the point where it goes into orbit are not so exact.

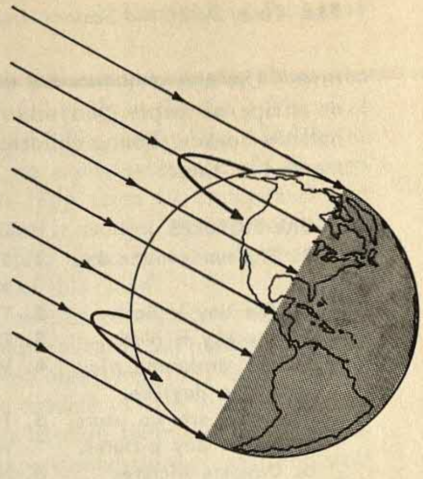
1. At this point, it may be within a little of the drag of the earth's atmosphere.
2. At this point, it must have been steered into a curved path.
3. At this point, its momentum must be greater than the pull of gravity. Its momentum must be about 17,000 miles per hour.

Because the initial momentum of the satellite, at the point where it goes into orbit, is somewhat greater than the pull of gravity, the advantage of the momentum will last long enough to elongate the closed curve. This makes the orbit an ellipse.

Because a temporary satellite cuts through a portion of air resistance on each trip, it gradually loses momentum. Its orbit grows smaller until it is completely within the earth's atmosphere. At this time it burns up.

9. A satellite passes over different parts of the earth each time it orbits because the earth is rotating beneath it. Some satellites are either too small or too distant to be seen without telescopes. Both man-made satellites and the moon shine by reflected sunlight. Tracking stations record the passage of satellites and collect their data.

10. To reach the moon, rockets or satellites must have a thrust great enough to provide an initial momentum of a little more than 25,000 miles per hour. The satellite must have enough momentum left at the 23,600-mile point to cross it and enter into the moon's gravitational field. The satellite must be aimed ahead of the moon to a point in the moon's orbit where the moon will be when the satellite arrives.



Chapter Twenty-Six

Time, Dates, and Seasons Around the World

The Spinning Earth

INQUIRIES

1. What are some of the differences between day and night?

2. What causes day and night? Why is the sun seen in the east in the morning and not in the west? Why does the sun seem to move across the sky from east to west?

3. How is time determined? What causes time to change? When does each new day of the week or date on the calendar begin?

4. Why must people change the time on the watches or clocks they carry when they travel far enough to the east or west? Why are no changes necessary when people travel due north or south?

5. Why is there a need for an International Date Line? What changes in time does a traveler make when he crosses this date line?

1. What are some of the differences between day and night?

Ask the children to make colored pictures of day and night. They may also enjoy collecting colored pictures from magazines that represent these two times. Arrange the pictures on bulletin boards. Place the caption "Day Pictures" on one board and "Night Pictures" on the other. How do the day pictures differ from the night pictures? Use a crayon to write the children's ideas on strips of paper and add the strips to the bulletin boards. Young children may make statements like these:

DAY PICTURES	NIGHT PICTURES
1. The sun is in the sky.	**1.** The sun is not in the sky.
2. The day is light.	**2.** The night is dark.
3. The sky is blue.	**3.** The sky is black.
4. We work and play in the daytime.	**4.** We sleep at night.
5. There are no stars in the day pictures.	**5.** There are stars in the night pictures.
6. Daytime pictures have bright colors.	**6.** Night pictures have dark colors.
7. Days are warmer.	**7.** Nights are cooler.
8. Days are noisy.	**8.** Nights are quiet.

The children's observations of differences between day and night may not always be true. Some children are likely to make such challenging statements as: "The sun is on the other side of the world at night." "I saw a red and yellow sky once." "My father works at night. He sleeps in the day." "In winter, days are cold." "When the moon shines, it's light at night."

On Friday, take the class out in the schoolyard to watch the sky. Take them to the *south* side of the school building (to the *north* side if you live in the southern hemisphere). Take a black crayon, an easel, and a large piece of paper. Ask the class to stand with their backs toward the building and to select three large, fairly distant, stationary objects which they see from this location. They should be objects, such as a house, tree, and pole. One object should be directly in front of them; another object to their right; and the third object to their left. Help the pupils to plan and draw a basic scene including the three selected objects. The scene could be similar to Fig. 26.1.

Duplicate ten copies of this basic scene for each pupil. On Monday, give each child one copy and have him print his name and the name of the day at the bottom. *As near noon* as possible, have each child take his crayons and his copy of the basic scene outdoors to the place where it was sketched. "Color the sky in the picture to match today's sky." Repeat the same procedure on Tuesday, Wednesday, Thursday, and Friday. Compare the skies pictured on the five days.

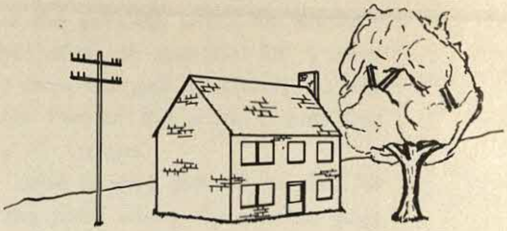


Fig. 26.1 Facing southward make a sample drawing similar to this figure.

The following week, find out whether any of the children have looked at the sky from the sketching area on their arrival or departure from school. "Did the sky look the same in the morning or afternoon as it did at noon? What was different?" Make five observations during one school day. Choose such times as (1) early morning, (2) mid-morning, (3) noon, (4) mid-afternoon, and (5) late afternoon.

Discuss the damage that may occur to the eyes if people look directly at the sun. Even on a cloudy or hazy day, one should not look directly at the sun. Let the children practice locating objects in the room without looking directly at them. Explain that this method always should be used to determine the position of the sun.

On a sunny morning, give each child five of the mimeographed scenes. The children can label them "early morning," "mid-morning," "noon," "mid-afternoon," and "late afternoon." At these five times, make brief trips to the sketching area. Locate the sun in relation to the three large objects. Record its location on the basic scene. Repeat this procedure until each child has five picture records of the sun's position in the sky.

Discuss the pictures the children made on the five different days. Find out why they colored the skies in their pictures differently. "When did the sky look blue? When was it not blue? What other colors did you use for sky? On which days were there clouds? On which days did the sun seem to be hidden?"

Also, discuss the five pictures that were made on the same day. Compare the five different positions of the sun in these pictures.

Provide experiences with the four basic directions (north, south, east, and west). Relate these directions to the school building. Develop the understanding that, if a person faces south, east is to his left and west to his right. Have the children label each of their *last* five picture records with E (east) on the left and with W (west) on the right. "In what direction did you record the sun early in the morning? Where did you see it late in the afternoon?"

Take the class outdoors and practice finding directions. Stand where they can see their school in front of them as they face north. Have them draw a picture of the school from this place. Label the east and west sides of the picture.

Now choose a clear, sunny day when shadows will be distinct. Return to the south observation area at early morning, mid-morning, noon, mid-afternoon, and late afternoon with black crayons and the mimeographed papers on which the children have previously recorded the position of the sun. Each time, have the children observe and record the location and length of the shadows cast by the three objects.

Ask the children to lay their five records in a sequence and compare the changes in the location and size of the shadows. Help them to see the relationship between the position of the sun and the size and location of the shadows.

Experiences similar to the ones suggested should help the children understand how the *sun's position in the sky can be used to tell time.* Large time blocks, such as early morning, mid-morning, noon, mid-afternoon, and late afternoon are easy to determine by observing the sun's position in the sky. It should also lead to an understanding of *how shadows can be used to determine time.*

Have the class make a sundial. Select an open area in the schoolyard that is exposed to sunlight. Lay a large sheet of white paper on the ground and push a pencil through the center of the paper into the ground. Four or five inches of the pencil should be visible above the paper. Weight the edges of the paper so that it will lie flat on the ground. Make brief trips to the sundial during the same five time periods. Use a felt pen to color the pencil's shadow on the paper. Write the time near each shadow.

Encourage the children to repeat the experience with the sundial at home on Saturday and bring their papers to school on Monday. Let those children who can tell time mark the shadows on the paper sundial hourly.

Choose a day when small clouds repeatedly obscure the sun. Have the children watch the sundial for changes that occur in the *brightness* of the paper and the *darkness* of the pencil's shadow as bright sunshine alternates with cloud cover. (Remind the children again about the danger of looking directly at the sun.) The class also should observe the paper, the shadow or lack of shadow *on a day when the sky is completely overcast.* Help them to understand that what they observe is caused by the very large cloud covering their area. As a result, their city is in the shadow of this cloud.

On the south side of your classroom, set up a three-dimensional replica of the outdoor area the children have been observing. This replica should include upright models of the three stationary objects the class used in their outdoor observations, a small paper-pencil sundial, east and west signs, and some paper clouds of various sizes. Darken the room. Show the children how they can hold a flashlight so that it will shine on this scene in the same way as the sun did in their outdoor observation area. Hold the flashlight to the east. Call attention to its location and to the shadows of the objects. Ask if the pupils can tell what time of day the model pretends to show. Use their picture records, showing the location of the sun and shadows, to check their answer.

When the children understand that they can repeat in miniature what they have observed outdoors, ask different ones to show the position of the "flashlight sun" for noon, late afternoon, and so on. Make a game of it. Let a child demonstrate any time of day he wishes and have the rest of the class guess what time it is. Use the paper clouds to show how cloud shadows darken the scene.

2. What causes day and night? Why is the sun seen in the east in the morning and not in the west? Why does the sun seem to move across the sky from east to west?

Experiences like these will help children to answer these questions correctly.

Fasten the *three-dimensional scene* from Inquiry 1 to a long strip of oak tag and place it on a table. Place the table in front of the class in the south area of the room. Let the children use a flashlight and the model scene to demonstrate their answers. *Do let them explore the inquiry, express and debate their ideas, and either accept or reject their personal solutions.* Try not to say, "That's right. Tim is wrong." Say, "Do you agree with Tim? What do you think, Susan? Show us your ideas, John."

Discuss ways in which the model scene can be made more nearly like the shape of the earth. (It is easy to roll and staple the long oak tag base to give the appearance of roundness, even though it is a roll instead of a ball.) See Fig. 26.2.

When the children object to the earth being shaped like a roll and insist that it is ball-shaped, have them cut from the oak tag base the section on which the three objects are mounted and tape it to a large beach ball. See Fig. 26.3.

To the question "What causes day and night?" children may propose solutions like these: (1) The sun goes around the earth. When the sun is on the side where the house is, it is day. (2) The earth goes around the sun. (3) The sun does not go around the earth. The earth turns.

Let the children demonstrate their ideas. (1) Raise the beach ball from the table and move the make-believe sun (flashlight) around the ball. Be sure that they observe that the basic scene is in the dark when the flashlight is under the ball. (2) Revolve the ball around the make believe sun with the basic scene facing the light. The children will observe that the basic scene is always in the light. (3) Spin the ball slowly in the beam from the flashlight. The basic scene is in the dark when it is turned away from the beam (see Fig. 26.4). Which hypothesis seems most acceptable? Very young children often hypothesize that it is the spinning or rotating motion of the earth that causes day and night.

Help build the concept that people live on more than one side of the world by adding more houses, people, and so on to the model. This will also help the children to see that when it is day for some people, it is night for others. They can see that the earth's spin or rotation causes day to change into night, and night into day. Some child will probably observe that the direction in which the earth turns makes a difference. Let them demonstrate their ideas. Help them to see that if the earth turns from west to east, the light from the sun will appear first to the east in the early morning, and last to the west as the end of the day arrives in the late afternoon. Make a diagram like Fig. 26.5 on the chalkboard. Have the children add arrows with colored chalk to show the direction in which they have been turning the earth. Help them to see that the arrow on the right shows that the earth is turning from west to east. Show that if the earth turned from east to west the sun would shine from the west in the morning and from the east in the afternoon. See Fig. 26.6. Make this diagram on the chalkboard. Help the children to see that if the earth turned this way, the arrows would show that it turned from east to west. Help the class to realize that only when the earth turns from west to east does the sun appear in the east in the morning and disappear in the west in the evening.

When the pupils become concerned because the house, tree, and pole in their three-dimensional model seem to be upside down, spend some time on the concept of gravity. They need to understand that *up* is away from the earth's center and that *down* is toward the center of the earth. (See Chap. 20, Inquiries 1 and 2.)

Send representatives from the class to every room in the school that has a globe. Ask the representatives to spin and examine these globes. They have been turning their beach-ball globe with its imaginary axis in a horizontal position. They will discover that the axis about which commercial globes spin is almost vertical. Help them to make the transition to this traditional illustration of the earth and sun by placing their beach ball in this position (see Fig. 26.7). Use a filmstrip projector light to represent the sun's light. Make sure the light from the projector floods one-half of the surface of the ball. Show that the earth has no base or table on which to rest and that it may be pictured either way. The children's method of spinning or rotating the earth was not wrong, but because books and globes show it this other way, it will be best for them to change their "beach-ball earth" to the traditional position. Check to make sure that they see that the sun will still appear in the east and disappear in the west, when the ball is turning from west to east.

Let the children play with their model of the earth and sun until all of them can demonstrate the change from day to night and from night to day. Be sure that they spin their beach-ball globe correctly. Call their attention to the morning and afternoon shadows made on the "beach-ball earth" by the projector and compare the position of these shadows with the recorded morning and afternoon positions of the outdoor shadows.

A piano stool that spins can be used as an "earth" on which a child can sit. Have the chil-

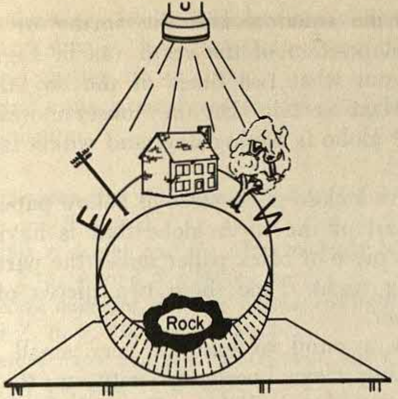


Fig. 26.2 Roll base on which model scene is fastened.

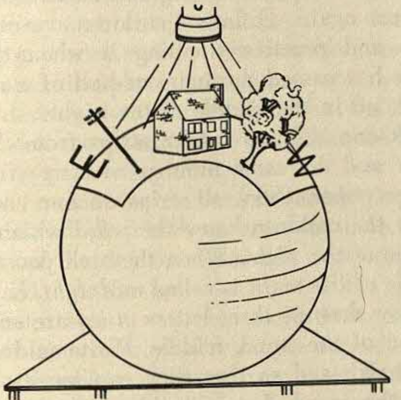


Fig. 26.3 Mount model scene on beach ball.

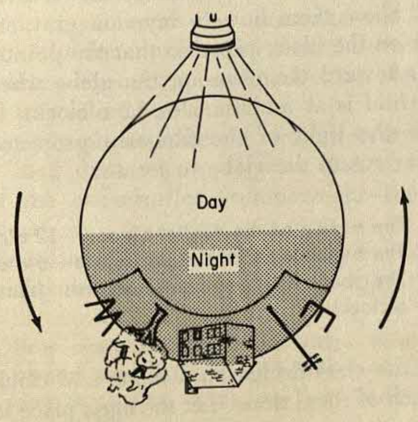


Fig. 26.4 Spin the model scene in the light of a flashlight.

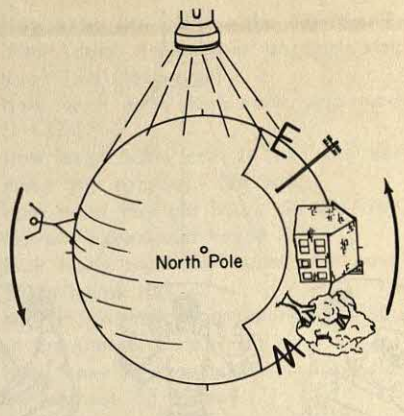


Fig. 26.5 The light shines first on the east when the model is spun this way.

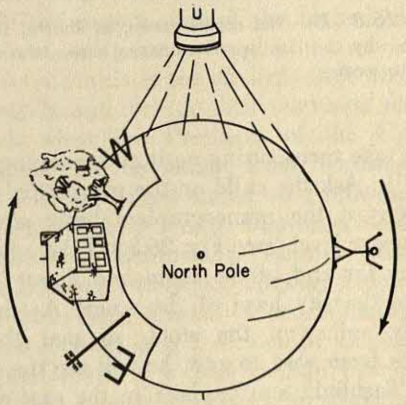


Fig. 26.6 The light shines first on the west when the model is spun this way.

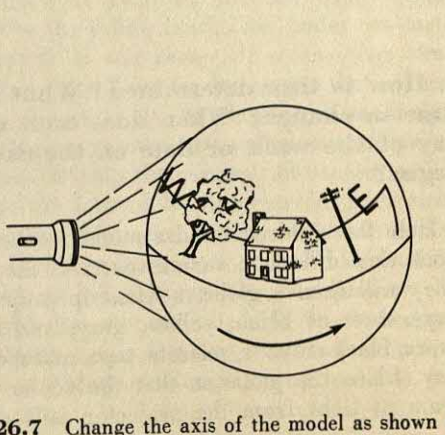


Fig. 26.7 Change the axis of the model as shown and spin the ball this way.

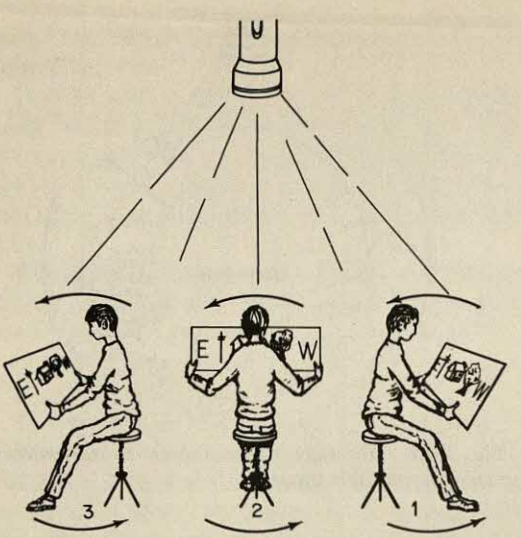


Fig. 26.8 Use the model scene, as shown, to demonstrate why the sun seems to move across the sky from east to west.

dren take turns sitting on it and spinning (rotating) it. Ask the child on the piano stool to hold a copy of the mimeographed basic scene just below eye level. (see Fig. 26.8.) Take a flashlight to the far end of the room and direct its light above the sky level of the scene. As the child slowly spins on the stool, so that the stool moves from west to east, he will see the light of the "flashlight sun" appear in the east and disappear in the west. The make-believe sun *will seem to move across the sky* even though the sun *does not move at all.* This happens because the earth on which he is riding is spinning or rotating.

3. How is time determined? What causes time to change? When does each new day of the week or date on the calendar begin?

Help the children build a model to show how clock time differs in various parts of the world. They will need a globe, a filmstrip projector, a large sheet of black, yellow, gray, and orange paper, black crayons, scissors, tape, and modeling clay. Place the globe so that the center of the beam of light from the projector falls directly upon the equator. Use the spring or autumn orbital position of the earth (as in Fig. 27.4). Find out what two times of the day they can see. Make certain that they observe which side of the globe is having day, and which is having night.

Have a child put a piece of yellow paper under the part of the earth globe that is having day and a piece of black paper under the part that is having night. Tape these two pieces of paper together.

Ask a pupil to make a very small ball of modeling clay. Locate his city on the globe. Place the clay ball there. Pretend that the clay ball represents a figure of a person. The children should take turns spinning (rotating) the globe from west to east to show how they ride on the earth from daytime into nighttime and then into daytime again. Different children can spin the globe and practice stopping it when the clay figure has passed through one-half of a night or is located in the middle of the night.

Ask one child to cut 12 strips from the gray paper and the same number of strips from the orange paper. Point all strips on one end. Find out if the children know the word which means middle of the night. When they tell you that the middle of the night is called *midnight,* help them to know that the three letters *m i d* are an abbreviation of the word, middle. Write midnight on the chalkboard so that they can see as well as hear the word. Let a child write the word—midnight—with a black crayon on one of the gray strips of paper. Ask someone in the class to show where the hands of the clock point when it is midnight. Write the number 12 on the same strip. Show them how to lay this gray strip of paper on the black paper so that the pointed end points toward the place on the globe where the clay child is at midnight, or 12 o'clock.

Use the light of the filmstrip projector and spin or rotate the globe to locate:

1. The middle of the daylight (noon—12 o'clock);
2. The beginning of the night (sunset—6 o'clock);
3. The beginning of the daytime (sunrise—6 o'clock).

Have the class decide on a name and clock time for each of these times. Let the class place labeled strips pointing to the position where the class has decided the clay child would be located at noon, sunset, and sunrise. Use gray strips for nighttime hours and orange for daytime.

Use the same procedures to develop each of these concepts:

1. *Afternoon* and the *afternoon hours* of 1, 2, 3, 4, and 5 o'clock;
2. *After midnight* and the *after midnight hours* of 1, 2, 3, 4, and 5 o'clock;
3. *Before midnight* and the *before midnight hours* of 7, 8, 9, 10, and 11 o'clock;
4. *Before noon* and the *before noon hours* of 7, 8, 9, 10, and 11 o'clock.

Write the proper information on the remaining strips of gray and orange paper and place them in their correct positions on the yellow-black base under the earth globe.

You may wish to develop the time words—*morning* and *evening*—for the hours before noon and before midnight. At this time, you may also wish to develop the understanding that the hands of the clock move around twice while the earth is spinning or rotating once.

When the children can turn the earth globe, so that the clay ball (child) is correctly placed for any time of the day or night, add a second clay ball (child) to the opposite side of the globe. This second figure will help children to understand how time in a country on the opposite side of the earth will be different from their time. Let the class practice with the two figures until they can see and say, for example, "When it is 4 o'clock in the afternoon for us, it is 4 o'clock in the morning for children who live on the opposite side of the earth."

Add more and more clay figures on the globe until the children understand that the time for each place depends upon where that place is located in relation to the sun.

Pretend to phone someone in a different country or in a distant part of your own country. During the conversation, compare the time in each place.

Refer to the 12 gray and orange paper strips to help the children answer these questions:

1. How many different time strips have you placed around the globe? (24)
2. How many time strips are there in the daylight? (12)
3. How many are there in the nighttime? (12)
4. What does the number on each strip tell you? (the clock time)
5. How much time does each strip measure? (1 hour)
6. How many hours does it take the earth to make one rotation? (24 hours)
7. How many daylight hours did the clay child in your experiment have? (12)
8. How many nighttime hours did your clay figure have? (12)
9. How many time strips point to the 50 states in the United States? (7)
10. How many different clock times would there be in these 50 states? (7)

Discuss what children in different states and countries might be doing when it is 2 p.m. in your classroom. Develop the understanding that people in the eastern part of the United States see televised ball games at *night* that are being played in California in the *daylight*. Ask why the people in Chicago turn on their television sets at 7 o'clock when the President of the United States speaks to the nation from Washington, D. C. at 8 o'clock. Find out at what time people would turn on their sets in Denver, Colorado; San Francisco, California; Juneau, Alaska; Yakutat, Alaska; Fairbanks, Alaska; Honolulu, Hawaii; and Nome, Alaska. (When Washington, D. C. is 8 o'clock, it is 7 o'clock in Chicago, 6 o'clock in Denver, 5 o'clock in San Francisco, 5 o'clock in Juneau, 4 o'clock in Yakutat, 3 o'clock in Fairbanks, 3 o'clock in Honolulu, and 2 o'clock in Nome.) Then use the classroom globe and the paper strips to find the answers. Locate each place on the globe.

Explain that each of the 24 paper strips fastened to the yellow black base under the earth globe *points to the center of a one-hour time zone*. Show the lines on the globe that extend from the North to the South Pole. Explain that these *imaginary* lines are called *meridians* of longitude. Develop the concept that these meridians also are located in the center of each time zone. Let the children count the meridians on the globe. (Be sure to use a globe that has 24 meridians on it.) Compare the meridians on the globe with the number of strips on the yellow black paper base. Develop the understanding that the meridians of longitude are used to tell time.

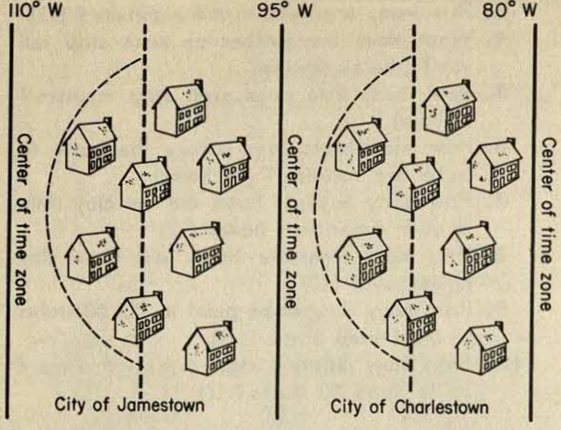


Fig. 26.9 A simplified time-zone map to show how and why regional adjustments are made.

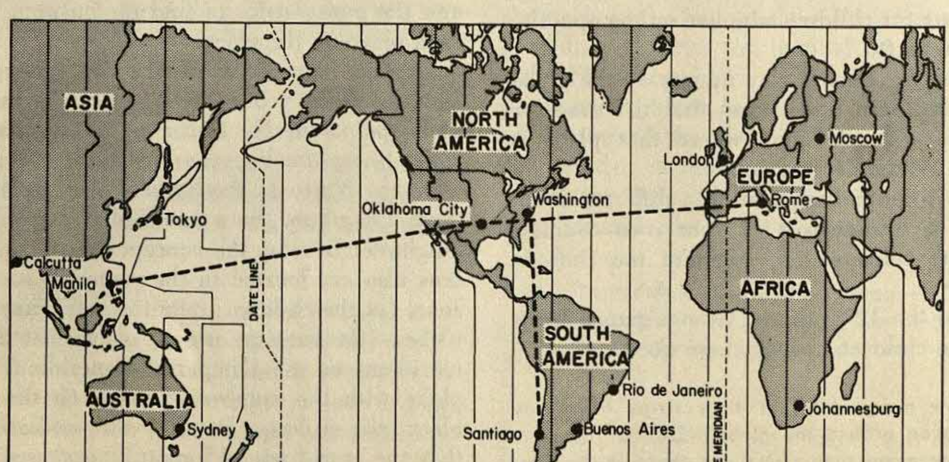
Some children should be encouraged to work with the measurement involved in dividing a sphere into 24 wedge-shaped pieces to represent the 24 time zones. Other children might cut meridians of longitude into the skin of apples, grapefruit, or other spherical fruits.

A third group of children might do the arithmetic involved in dividing the 360 degrees of the circumference of the globe by the 24 meridians to discover that there are 15 degrees of longitude from the center of one time zone to the center of another. They could verify their answer by finding the number of degrees between the meridians on the globe they have been using.

Another group might read about the international agreement pertaining to the location of the *prime meridian* which extends through Greenwich, England. Have the children of this group share the information with the class and show where Greenwich is located on the globe.

Develop the difference between meridians of longitude and time zones. A one-hour time zone is 15 degrees wide and a meridian of longitude extends through the center of it. Have the children construct a time zone map similar to Fig. 26.9. Help them to agree on some adjustment of the time zone boundaries that will allow all the people in the imaginary cities to have the same time. Use dotted lines for the adjustments. The children should learn that meridians of longitude are determined by international agreement and that time zones can be adjusted by federal, state, or local authorities. Discuss the need for flexibility between adjacent time zones. Have the children compare the simple local adjustments they made in Fig. 26.9 with the kind of adjustments made by authorities on a time zone map of their country. (see Fig. 26.10.) Let them decide why these adjustments were made. From this discussion they should realize that these changes were made to eliminate the confusion that would result in places that are located in

Fig. 26.10 Time zone map of the world. *Courtesy U.S. Naval Oceanographic Office and Current Science.*



parts of two time zones. Have the children imagine what would happen if this situation existed in their city. They should also learn the name of the time zone in which they live. The United States has seven time zones. Canada has six. It is interesting to note that 48 of the states in the United States lie in four time zones and that the state of Alaska, also, has four time zones. Name them.

UNITED STATES TIME ZONES

Name of Zone	Centered on Meridian
1. Eastern	75 degrees west
2. Central	90 degrees west
3. Mountain	105 degrees west
4. Pacific (also called Juneau)	120 degrees west
5. Yukon	135 degrees west
6. Alaska (also called Honolulu)	150 degrees west
7. Nome	165 degrees west

CANADIAN TIME ZONES

Name of Zone	Centered on Meridian
1. Atlantic	60 degrees west
2. Eastern	75 degrees west
3. Central	90 degrees west
4. Mountain	105 degrees west
5. Pacific	120 degrees west
6. Yukon	135 degrees west

Help the pupils conclude that each *date on the calendar* represents one complete rotation of the earth and that during this one rotation they will have both darkness and daylight. Help them to associate one rotation with each day of the week. For example, on Monday the earth rotates once. In a week, it rotates seven times. Part of Monday will be night, part will be daylight. Establish the fact that each new day of the week, or calendar date, begins immediately after midnight. Develop the idea that the 12 hours from midnight to noon are referred to as a.m. (ad meridian or before noon) and that the 12 hours from noon to midnight are referred to as p.m. (post meridian or after noon). Ask *one* of the pupils to write a.m. and p.m. on the paper time strips. To establish the fact—that each date begins at night, changes to daylight, and ends with night—have one child draw squares around the names of the days of the week. Use perpendicular lines to divide each square into fourths. Ask a second child to color the first quarter of each square with black crayon, the next two quarters with yellow crayon, and the last quarter with black. Emphasize the following concept by spinning the globe and observing that: part of Monday is nighttime and part is daytime; part of Tuesday is nighttime and part is daytime, and so on. Then practice turning the globe and saying aloud, when the clay figure passes the midnight point, Monday begins, Tuesday begins, and so on. After the class has played this game for a while, ask them, "If it is one minute after 12 o'clock midnight on Monday in your time zone, what day is it for the people living in the first time zone to the west?" (Sunday.)

4. Why must people change the time of the watches or clocks they carry with them when they travel far enough to the east or west? Why are no changes necessary when people travel due north or south?

How many children in the class have had a real experience of changing the time of their watches on long trips? Have these children relate their experiences with time zones.

Plan a make-believe plane trip to some country that is located to the east of you. Ask those children who own watches to bring them to school. Also, obtain two small clocks. Model a tiny clay figure of a child and press it to the area on a globe that represents where the children live. Use the watches, clocks, and globe with the paper strip time zones to obtain a visual picture of the trip.

Choose an airport in the time zone for a port of departure and another airport in some country to the east as a port of arrival. Assume that the departure time is 10 a.m. and the travel time four hours. At 10 a.m. set one of the clocks and the children's watches. Use the paper strips and globe to answer this question. When it is 10 a.m. for you, what time is it in the country to which you are going? Set the second clock for this time. Turn on the projector light. Rotate the globe so that the time will be 10 a.m. for the clay figure located in the children's time zone. Place each of the clocks in its proper time zone under the globe.

Four hours later, in the school day, have the children pretend that they are landing at the port of entry. Ask them to look at their watches and compare the time with the clock in their home port. Rotate the globe so that it will be at 2 p.m. for the clay figure. Move each of the clocks to their new position (four strips to the east). Check the clock time in the port of arrival. Ask the children why their watches do not agree with the clock in the port of arrival. Let them decide how they must set their watches while they are in this eastern city. Perhaps they can tell you whether they have lost or gained time and what will happen when they return home.

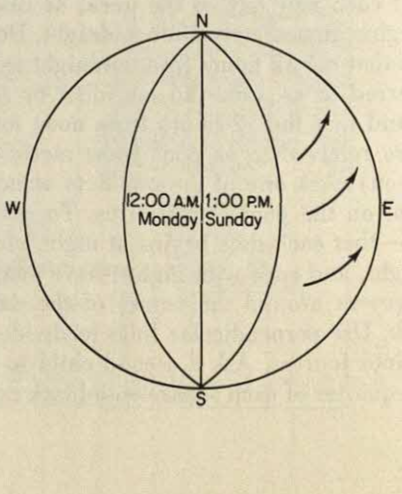
Plan a similar trip to the *west* and discover the time change that occurs. Children who live in the eastern section of the United States will be surprised to discover the time changes that occur on a *3-hour flight* from New York City to California. Let them explain why they can leave New York at breakfast time and arrive in California in time for a second breakfast. Ask them what would seem to happen if they flew from New York to California in *less than 3 hours.* (They would seem to arrive before their departure time.) Plan imaginary trips to other parts of the world. Also, take trips north and south across the equator. Discuss whether there are time changes if you travel on foot, by automobile, by train, by submarine, by boat, or by rocket.

5. Why is there a need for an International Date Line? What changes in time does a traveler make when he crosses this date line?

Ask a child to place a small clay figure on the area of the globe in which his class lives. Rotate the globe until this figure is at the 12 p.m. time strip. (See model construction, Inquiry 3.) This is midnight. Choose the name of a weekday. In this explanation, it is assumed that the class chose Sunday. It is midnight on Sunday for the clay figure. Have the children tell the clock time and the name of the day in the next time zone to the *east.* (It is 1 a.m. on Monday. It was midnight in this time zone one hour ago.) Find out if the class knows what day and time it is in the zone immediately to the *west* of the clay figure. (It is Sunday 11 p.m.) Help the class name the day and time for 12 time zones to the east of the clay figure. Because they have learned that clock time is set ahead one hour as they cross each succeeding time zone to the east, their list will be like this one: (1) Monday, 1 a.m.; (2) Monday, 2 a.m.; (3) Monday, 3 a.m.; (4) Monday, 4 a.m.; (5) Monday, 5 a.m.; (6) Monday, 6 a.m.; (7) Monday, 7 a.m.; (8) Monday, 8 a.m.; (9) Monday, 9 a.m.; (10) Monday, 10 a.m.; (11) Monday, 11 a.m.; (12) Monday, 12 a.m. or noon. In the 12th time zone, place a marker with 12 a.m. or noon Monday, written on it. Then help them list the eleven time zones to the *west* of the clay figure. Since it is 12 p.m. or midnight, Sunday in the clay figure's time zone and clocks are set back one hour as you cross each succeeding time zone to the west, their listing will be like this one: (1) Sunday, 11 p.m.; (2) Sunday, 10 p.m.; (3) Sunday, 9 p.m.; (4) Sunday, 8 p.m.; (5) Sunday, 7 p.m.; (6) Sunday, 6 p.m.; (7) Sunday, 5 p.m.; (8) Sunday, 4 p.m.; (9) Sunday, 3 p.m.; (10) Sunday, 2 p.m.; (11) Sunday, 1 p.m. Place a second marker, with Sunday, 1 p.m. written on it, on the adjacent strip to the east of the first marker. The two markers, one labeled Monday, 12 a.m. or noon and the second one, to the east, labeled Sunday, 1 p.m., are in adjacent time zones as shown in Fig. 26.11. Ask the children what seems to be wrong. (It seems that the time zone *east of Monday, 12 noon* should be *Monday, 1 p.m.* instead of *Sunday, 1 p.m.*) Have the children check again the day of the week and time counts in both directions. (They will arrive at the same inconsistent answer.)

Suggest that they count six time zones to the east and 17 to the west of their own time zone to find out whether the inconsistency still occurs.

Fig. 26.11 A diagram to show the need for an International Date Line.



(It does.) Where the zones counted east meet those counted west, this inconsistency will exist. Even if the pupils count 23 time zones in the same direction, they will obtain a similar result. Let the pupils try this enough times and with enough combinations that make 23 to be sure that *an inconsistency always results.* Even if they start counting with a different time and day, they will find the same problem of two adjacent time zones having two different days of the week.

Discuss the inconvenience and confusion that would result if these two adjacent time zones, with two different days of the week, were located in a densely populated area. Help them to realize that this difference in the days of the week cannot be avoided. The best way to solve it is to locate the two zones in which the change of date occurs, where it will cause the least inconvenience and confusion. Ask them to search the globe for a place in which they believe the inconsistency could best be located. When they have decided that somewhere in the Pacific Ocean would be the best location, ask them to see if they can find such a place. (They will find the International Date Line located on or near the 180-degree meridian.) Be sure that they observe the zigzag adjustment lines that are drawn around continental land masses and groups of islands. Let the pupils decide the reason for these adjustments and why this date line would have to be established by international agreement.

Have the students pretend to cross the International Date Line by ship or plane. For example, if they approach it from the west, on Tuesday morning it will be Monday morning the moment they cross it. They will have Monday over again and thus gain a day. If they approach the date line from the east on Thursday afternoon, it will be Friday afternoon the moment they cross it. They will skip or lose a day. In actual practice, the change is made at night regardless of the true moment of crossing.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. The sun is in the day sky, not in the night sky. The sun makes day lighter than night. Days are lighter and brighter when there no clouds. Clouds between the sun and earth cause cloud shadows on the ground. The sun is seen in different parts of the sky at different times of day. It is in the east in the morning and in the west in the afternoon. People can tell time by the position of the sun in the sky. They can tell time by shadows.

2. The sun lights only one side of the earth at a time. The lighted side is called day. The other side of the earth is dark. The dark side is called night. When one side of the earth is having day, the other side is having night.

The earth turns, spins or rotates. The spin (rotation) of the earth causes the lighted (day) side to move around into the dark and the dark (night) side to move into the light. So long as the earth spins or rotates, day and night will always follow each other. The sun always appears in the *east in the morning* and disappears in the *west in the afternoon.*

The earth always spins (rotates) in the same direction. It spins (rotates) from west to east. If the earth rotated from east to west, the sun would appear in the west in the morning and disappear in the east in the afternoon. The sun does not move across the sky from east to west, *it only seems to do this.* The spin (rotation) of the earth *causes the sun to seem to move across the sky.*

3. The time of day is determined by the time zone in which you live. The earth's rotation causes changes in time. The earth is divided into 24 one-hour time zones. Meridians of longitude are imaginary lines that extend from the North to the South pole. There are 24 meridians of longitude on most globes.

A meridian of longitude marks the center of a time zone. The meridians of longitude on a globe can be used to determine the time in any part of the world. A time zone is 15 degrees wide. Each new calendar date, or day of the week, begins immediately after midnight.

4. When you travel to a new time zone, you must set your watch to the time of that zone. If you travel east, you set your clock ahead one hour for each time zone you cross. If you travel west, you set your time back one hour for each time zone you cross. If you travel north or south, you remain in the same time zone.

5. There are *two times* when the day of the week or calendar date changes. (1) *When midnight arrives* every 24 hours because of the earth's rotation, most countries change their day of the week and date. (2) *When the International Date Line is crossed by travelers,* the day of the week and date change. On a spherical earth, an International Date Line is necessary to provide a location where this second change can be made. By international agreement, this place is called the International Date Line. This date line was established on or near the 180-degree meridian because this location affects the fewest number of people. A traveler crossing it from west to east gains a day. A traveler loses or skips a day when he crosses the date line from east to west.

Chapter Twenty-Seven

The Orbiting Earth and Its Seasonal Changes

INQUIRIES

1. Which rays of the sun heat and light the earth ?

2. How are years measured ? How are years divided ?

3. As the earth orbits the sun, where does its North Pole always point ? In what directions in relation to the sun does the earth's North Pole point in the course of one orbit ? At how many places in the orbit does it reach its maximum change ? With what is each quarter of an orbit associated ?

4. What are the general differences in the four seasons of the temperate and polar regions ? In general, what causes these differences ?

5. Where in its orbit is the earth located on or about June 21 ? In the Arctic, what season begins on or about June 21 ? In the Antarctic, what season begins on or about June 21 ?

6. Where in its orbit is the earth located on or about December 21 ? What season begins on or about December 21 in the Arctic ? In the Antarctic ?

7. Where in its orbit is the earth on or about March 21 and on or about September 21 ? What seasons begin on or about March 21 and on or about September 21 in the Arctic ? In the Antarctic ?

8. How do seasons in the north and south temperate regions compare with each other and with the season in the nearest polar region ?

9. Between what latitudes are the Tropic Zone, the North and South Temperate Zones, and the North and South Frigid Zones located ? What determines the location of the zone boundaries ?

10. In the Tropic Zone, how do the number of hours of daylight and darkness vary on or about March 21, June 21, September 21, and December 21 ? What effect does this have on seasons in the tropics ?

11. How many hours of daylight and darkness does your region have on or about March 21, June 21, September 21, and December 21 ? What regions have the greatest difference in the length of day and night ? What regions have the least difference in the length of day and night ? Between what dates are the days longer than the nights for your region ? Between what dates are the nights longer than the days for your region ? What causes the length of day and night to change ?

12. What is the difference between direct and indirect or slanting light rays ? What can we use to observe this difference ?

13. Why do direct rays from the sun warm an area more than indirect or slanting rays ?

14. Where do the sun's rays strike the earth directly ? When do they strike these areas directly ? What parts of the earth receive only indirect or slanting rays from the sun ? When do slanting rays strike these areas with less slant ? More slant ?

15. Why does the amount of slant of the sun's rays vary with the time of day ? Why does the amount of slant of the sun's rays vary with the position of the earth in its orbit ? Why does the amount of slant with which the sun's rays reach the earth vary with different latitudes on the earth ? Why do the seasons change with changes in the angle at which the rays are received ?

16. What effect does the elliptical shape of the earth's orbit have on the seasons ?

17. What causes seasonal changes ?

1. Which rays of the sun heat and light the earth?

Tell the children that the radiant sun sends out *many kinds of rays.* Ask them to guess the names of *two* of these rays. They will remember that the earth receives light and heat from the sun and suggest the names—light rays and heat rays.

Show the class how to use a glass prism to separate the colors in sunlight (see Fig. 29.1). Help them to see that the colors appear in this order: red, yellow, green, blue, and violet. Let them "catch" these rainbow colors on a piece of white paper and color the area of the paper where they appear with matching colors of crayons.

Ask several members of the class to make a two-dimensional model to illustrate what they learned from their experiment with the glass prism. The model could be made like this. Fasten a large piece of black paper on the bulletin board. Cut a large triangle from a piece of clear transparent material and paste it in the center of the paper. Draw lines with white chalk to represent the light rays (white light) entering the prism and use different colors of chalk to show the spectral colors emerging from the prism.

Choose another group of children to show what they found out about white light. Have them insert additional toothpicks of the spectral colors into the sun model.

Ask the children where and when they have previously seen these rainbow colors. They may say that they saw them in the sky during or just after a rain, in the spray from a hose or sprinkler, or when the sun shines through water. Get their ideas about what kinds of things separate sunlight into the colors of the spectrum. (Water, water droplets, ice, certain shapes of glass, oil drops, and soap bubbles.) Some children may wish to experiment with glass tanks of water or large rectangular blocks of ice, which can be frozen in kitchen pans. Others may want to experiment at home with the spray from a hose or sprinkler, on both sunny and cloudy days.

Have the children help you prepare an experiment to do outdoors on a clear, sunny day to discover whether there is enough heat energy in sunlight to burn or melt certain things. They should collect bits of cotton, tissue paper, dry bread crumbs, candles, wax crayons, a magnifying glass, and a watering can filled with water. Before the trip try to burn things by using a magnifying glass to concentrate the rays of light. A concrete sidewalk is a good place to do this experiment. Place the material to be tested on the sidewalk where it will be exposed to bright sunlight. Hold the magnifying glass above the material and adjust its position until the sun's rays passing through the glass are concentrated into a small red spot about the size of a pin head. In a few seconds, the testing material will become hot enough to burn or melt. After the necessary skill is acquired, help the class test the small pieces of materials they have collected. Emphasize the ideas that the magnifying glass *concentrates or focuses* the sunlight into a very small area and that the rays that cause these things either to burn or to melt are called *infrared rays*. Use the watering can to put out any of the little fires that are started, even though it does not seem necessary to do so, and ask the children to clean up any debris left from their experiment.

Have some of the children make a two-dimensional model of the experiment they did with the magnifying glass. Pin another sheet of black paper on the bulletin board. Cut a circle from a piece of clear, transparent material to represent the magnifying glass and paste it on the paper. Use white chalk to represent the light rays and dark red chalk to represent the infrared rays entering the magnifying glass. Use the same colors of chalk to show how these rays are converged into a small red spot that is hot enough to burn or melt some kinds of materials. Also, pin up samples of the materials the children tested.

Ask another group to add some dark red toothpicks to the model of the sun to represent the infrared rays traveling outward from the sun in all directions.

Have the class find out whether window glass can be used to burn or melt things. Repeat the procedures used in the previous experiment with the magnifying glass to ascertain whether the sun's rays will also burn or melt the samples on this day. Then, substitute for the magnifier, a piece of window glass, which is the same size and shape as the magnifying glass, and test the samples again. The children will observe that the sun's rays pass through both of these glasses, but the window glass will not concentrate or focus the sun's rays. Ask the children to look and feel both the window glass and the magnifying glass. Find out whether they notice the difference between them. (The window glass is flat; the magnifying glass bulges or curves outward like a ball.) Have the children try other shapes and sizes of magnifying glasses to find out whether they will also focus the light rays. (They will.) A magnifying glass is one kind of *lens*. A magnifying lens concentrates or brings the rays in sunlight to a focus.

Have the children make a third two-dimensional model to show how visible and infrared rays in sunlight pass through window glass without being either concentrated or separated into colors in the spectrum.

Have one of the children apply a thick mixture of black water paint to the outside of one part of a windowpane that receives direct sunlight. When the sun is shining on both the painted and the unpainted areas of the pane, have the children feel the inside of both parts of the pane. The part that is painted will feel warmer than the part that is not. The black paint on the pane absorbed more rays than the clear glass.

Use a magnifying glass to find out whether enough light rays and infrared rays pass through window glass to burn or melt things. Collect the same materials that were used in the previous experiment with the magnifying glass. Place the materials to be tested in a metal pan and try to melt or burn them with a magnifying glass. (They can be.) Vary the experiment by taping white tissue paper over the outside of the windowpane. Feel the windowpane. Test the same materials. Why doesn't the magnifying glass collect and concentrate enough of the rays to cause burning or melting? (The tissue paper absorbed some of the rays.) Experiment with filter materials other than white tissue paper.

Caution the children about the careless use of a magnifying glass to burn things. A magnifying glass could cause as much damage as a match. Be sure they understand that a magnifying lens collects the sun's rays and brings them together into a very small area. This causes the material on which they strike to become *very much hotter* than it would get by just lying in the sunshine and *absorbing* the rays that normally spread out over a much larger area. Ask the children to explain why glass couldn't be used for window-panes if it *concentrated* the sun's rays that pass through it. (The concentrated rays would set on fire the things inside buildings that were not fire-proof.)

Explain to the children that people's eyes cannot see infrared rays the way they see the colors that are in white light. Be sure that they understand that they included these rays in their models to *indicate* that they are present in the rays of the sun. Help them develop the concept that the sun gives off many kinds of rays. Some of these rays are *visible* but many more of them are *invisible.* The *light rays* or *visible rays* make it possible for us to see things. These rays are called the *visible spectrum* or just the *spectrum.* There are many different kinds of rays that we cannot see. These rays are invisible. Infrared or "heat rays" are one kind of invisible ray given off by the sun.

Guide a discussion toward the building of the concept that there are sources of radiant energy on the earth as well as on the sun, which can be made to produce light and heat energy. Lamp bulbs are like small suns because they give off rays in all directions. Some of the children will be acquainted with "heat lamps" or infrared lamps that produce infrared rays, which make their skin feel warm when it absorbs them. Make certain that the children understand that rays travel *from the radiant object* to the object that receives them. Have them look at the three-dimensional model of the sun and the make-believe toothpick rays. Remind them that the sun's rays travel millions of miles before they strike the earth. The rays given off by the lamp and infrared bulbs travel from the bulbs to the objects that are lighted and heated by them. *A radiant object can light and heat another object without touching it.*

Encourage some of the pupils to locate information about the use of infrared rays to "see objects" (the sniperscope) and to take pictures (infrared film and flashbulbs) of objects in total darkness. Invite a photographer to take pictures of the class with infrared sensitive film.

Let the pupils speculate as to whether the infrared rays given off by the sun or by other hot sources of radiant energy can be used for cooking and heating purposes, even when there *is no direct contact* with the *hot radiant object.* Have them find out whether their surmises are correct by interviewing or corresponding with several firms specializing in the sale or manufacture of radiant heat appliances. Also, suggest that some of the class investigate the use of infrared rays to treat and detect some kinds of diseases.

2. How are years measured? How are years divided?

Check the children's concepts of a year. Have different children carry the globe around the "sun-ball" to show how many orbits the earth makes in (1) one year, (2) three years, (3) four years, (4) one-half year, and (5) one and one-half years, and so on. A child may also enjoy showing how many orbits the earth has made since he was born and having the class figure out how old he is.

When the children have had experiences similar to the preceding ones, they probably will have noticed that there are *two possible directions* in which the earth could orbit the sun. If they have not made this observation, raise the issue and help them discover the direction in which the earth revolves around the sun. Review Inquiry 2 in Chap. 26, in which the concept of the earth's *west to east* rotation is developed. Help them deduce that the earth orbits the sun in *one direction.* Also, encourage them to guess the direction. Ask the children to check their assumption with their science books. After they have learned the correct direction in which the earth orbits the sun, have them take turns orbiting the globe around the basketball sun in this direction.

Encourage some of the children to read and discuss some of the information they find about the orbits of other known planets in the solar system. They also might show one reason why a Mercury- or Venus-year is shorter than an earth-year and why all the planets beyond the earth have longer years than the earth. (The orbits are smaller for Mercury and Venus and longer for the others.) Ask these children to make a chart showing the length of each planet's year in earth-time (1 earth year is about 365 days). (See Table 22.1 for the orbital time of the other eight known planets.)

Use a calendar to show that a year is divided into 12 months. Find out whether the children know the names of the months and can say them in sequence. Have each child make a list of the months and learn to spell them.

Ask each child to bring a calendar to school which shows all the months of the year. Also, make sure that calendars for years having 366 days (leap years) as well as calendars having 365 days are available for the class to use. Have each child use his calendar to find and to record the number of days in each month and compare his list with other children's. Their records should show that January, March, May, July, August, October, and December have 31 days, and that April, June, September, and November have 30 days. Their records will vary for the number of days in February. Children who are using calendars for years containing 365 days will have recorded 28 days for February and those using leap year calendars will have credited February with having 29 days. Ask the children to think of several ways in which they can use their records to find the total number of days in a year. (They can do this by (1) counting the number of days, (2) adding the number of days in each of the twelve months, and (3) multiplying 7, the number of months that contain 31 days, by 31; by multiplying 4, the number of months that have 30 days, by 30; and, adding these answers to the number of days in February—28 days except in leap years, when there are 29.) Their answers will vary depending upon whether the date of their calendar year is divisible by 4 or not. Calendar years that are divisible by 4 contain 366 days and are called leap years; other years contain 365 days. Help the class develop the concept that every fourth year a day is added to the calendar year and that this extra day is added at the end of February as February 29th. They will have fun with the idea that there is a February 29th only once every 4 years and may wonder about birthdays for people born on this date. Let them find out if anyone in their school has a birthday on February 29th. If there is someone, invite this person to visit the room and tell what he does about celebrating his birthday during the three years out of every four when there is no February 29th. Help the class understand that books which describe a year as 365¼ days are correct. The earth actually spins, or rotates 365¼ times as it orbits the sun once. Show how 365¼ is an average of 365, 365, 365, and 366. Because the smallest unit of time which can be listed on a calendar is one day, these ¼ turns of the earth are not counted until one whole day accumulates.

Discuss some of the undesirable features of a 12-month calendar year.

1. Weeks begin on different dates of the month.
2. Months begin and end on different days of the month.
3. Holidays, year after year, do not always occur on the same date or the same day of the week.
4. Holidays sometimes occur in the middle of the week. If they occurred at either the beginning or at the end of the week, more people could enjoy long holiday weekends.

Tell the class about the 13-month calendar that has been proposed for overcoming the handicaps of the one now in use. Have them compute the number of days in each of these 13 calendar months for years containing 365 days and 366 days. (There would be 28 days in each month, plus one extra day a year in calendar years containing 365 days, and 28 days in each month, plus two extra days a year in leap years.) Also, have them figure the number of weeks in a month and the number of weeks in a year. (Four weeks in every month; 52 weeks plus one or two extra days in a year.) Develop the idea that the extra one or two days could be given special names, such as New Year's Day and Leap Year Day. New Year's Day would be an added day each year and Leap Year Day added as a second extra day every four years. If this were done, it would be a simple matter to organize a more workable calendar. Ask a group of children who enjoy working with numbers to design a 28-day, 13-month calendar and present it to the class for evaluation. Let them wonder why this was not done before.

Have the children name the four seasons of the year that occur in the temperate and frigid zones of the world. (Spring, Summer, Autumn, and Winter.) Let them figure the number of months in each season (3) and use calendars and almanacs to find the date when each season begins (on or about March 21, on or about June

21, on or about September 21, and on or about December 21).

3. As the earth orbits the sun, where does its North Pole always point? In what directions in relation to the sun does the earth's North Pole point in the course of one orbit? At how many places in the orbit does it reach its maximum change? With what is each quarter of an orbit associated?

Review the learning—the earth rotates on its axis. Emphasize the idea that this axis is an imaginary pole that extends through the center of the earth. Its north end is called the North Pole; its south end, the South Pole. Locate these two ends of the axis on a globe.

A knitting needle inserted through the center of an orange can be used to illustrate an axis. Hold the needle in a *vertical* position and spin or rotate the orange on it. Spin the globe. Ask the children to compare the way the globe spins with the way the orange spins. What is different about the globe's axis? (Its axis is tilted or inclined away from the vertical.) Have several members of the class check other globes to see if they are inclined or tilted on their axes. Ask the children why globes are manufactured with inclined axes. (Because the earth's axis is inclined.)

Develop the concept that the ends of the axis can be thought of as pointers. Move the globe to different areas of the room. Call attention to the part of the room to which the globe's North Pole points. Help the class visualize the earth in space. Ask, "To what in space could the earth's North Pole point?" (The sun or other stars in space.) Tell the children that wherever the earth is in its orbit around the sun the North Pole of its axis points toward the North Star (Polaris). Discuss the shape of stars. (Stars are round like our sun.) Have one of the children cut a round, yellow circle from a piece of paper to represent the North Star. Ask the school custodian to tape this paper star to the ceiling in the northern part of the room.

Tell the pupils to make a fist around a pencil. The fist represents the earth and the pencil its axis. Have the children, carrying their "fist earths," walk around a basketball sun always keeping the North Pole of the "pencil axis" pointed toward the model of the North Star. Vary this experience by having them take turns orbiting a small globe around the basketball sun, being always careful to keep the globe's North Pole pointed toward the model of the North Star.

Repeat the preceding experience in which a student, orbiting the globe about the basketball, at the same time carefully keeps the earth's North Pole aimed at the model of the North Star. Ask the remainder of the class to observe where the North Pole points in *relation to the sun.* They will discover that there is one place in the orbit where the North Pole is inclined at a maximum *toward the sun;* another where it is inclined at a maximum *away from the sun;* and two places where it points *neither toward nor away from the sun.*

At these four places in the orbit, have the children put markers indicating this information. Make certain they see that the markers divide the orbit into four quarters and realize that each quarter section of the orbit represents one quarter of a year, or three months.

Ask the children to develop a theory based on this information. (Each of these four quarter sections of the orbit seem to be associated with one of the four seasons common to all temperate and polar regions.) The four locations at which the orbit is divided must indicate the four points (month, day, hour, and minute of the year) at which each of the four seasons begins.

4. What are the general differences in the four seasons of the temperate and polar regions? In general, what causes these differences?

Discuss the general differences between summer, winter, spring, and autumn. (With the exception of tropical regions, summers are warmer than winters; the mild spring season occurs at the end of the winter cold and before the summer heat; and the season of autumn occurs at the end of the summer heat and before the winter cold.) Discuss again where the earth gets its heat energy. (The sun.) If necessary, review Inquiry 2. Now ask the class why they think summers are warmer than winters. (More heat and light energy are received from the sun.)

The greater heat and light energy received in summer is caused by a combination of two factors: (1) there are more hours of day than night, during which the regions of the earth that are having summer receive heat and light energy from the sun; and (2) the energy received is more intense. Factor number 1 will be developed in Inquiries 7, 8, 9, 10, 11, 12, 13, and 14; factor number 2 in Inquiries 15, 16, 17, and 18.

5. Where in its orbit is the earth located on or about June 21? In the Arctic what season begins on or about June 21? In the Antarctic what season begins on or about June 21?

To help the children discover the physical reasons why *the number of hours of daylight and darkness vary with the seasons* in the temperate and polar regions, use experiences like the ones here and in Inquiries 8, 9, 10, and 11.

Place a small clay figure on the globe near the North Pole. Replace the "basketball-sun" with a filmstrip projector. Darken the room and direct the light from the projector on the globe so that the side facing the projector is completely lighted. Slowly orbit the globe counterclockwise around the projector. Constantly keep the globe spinning and carefully keep its North Pole always pointing toward the North Star. Follow the earth with the beam of light from the projector. Stop orbiting the globe when it reaches the position in its orbit where the North Pole *is inclined at a maximum toward the sun,* as well as toward the North Star. Continue, however, to rotate the globe, until the pupils observe that the clay figure is in sunlight through *one complete rotation or for 24 hours and that there is no nighttime* (see Fig. 27.1).

Help the children understand that at the time when the earth reaches this point in its orbit, people (represented by the clay figure) who live or are stationed in the Arctic receive the *maximum number of hours of sunlight (24).* Therefore, they are having *their longest day of the year.* Because the sun shines for 24 hours on the longest day in the year in the Arctic, the maximum number of hours of heat and light energy from the sun is being received.

The children should remember or be helped to recall that the globe is at *one of those four locations which they previously identified as the beginning of a season.* "In the Arctic, what season is beginning?" (Summer.) They have also learned (see Inquiry 4) that the four seasons begin on or about the 21st day of March, June, September, or December. Ask, "What date is it in the Arctic?" (On or about June 21). "In relation to the sun, where is the South Pole pointing?" (Away from the sun.)

While the children are having the experience shown in Fig. 27.1, be sure *they* make the following observations:

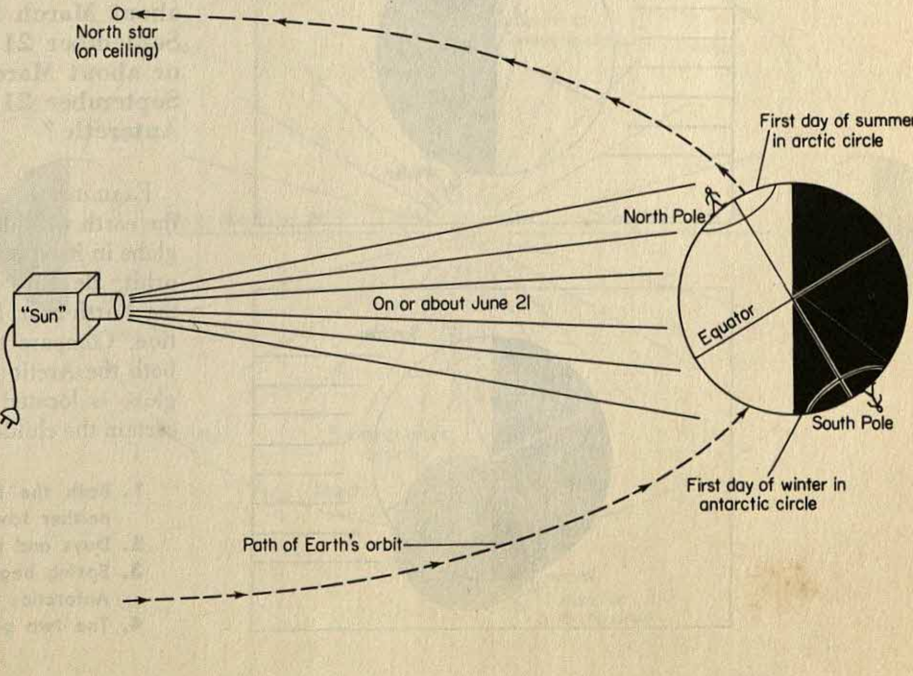
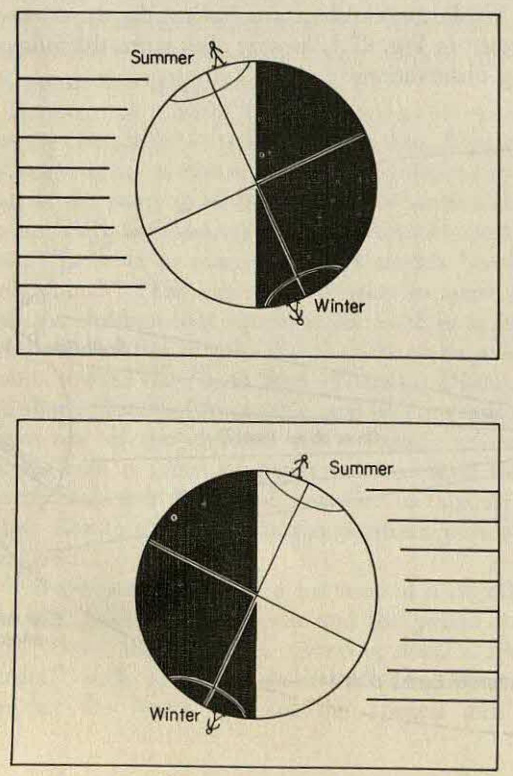


Fig. 27.1 Position of earth in its orbit on or about June 21.

1. When the North Pole is inclined at a maximum toward the sun, the South Pole is inclined at a maximum away from the sun.
2. When the Arctic receives the maximum number of hours of heat and light energy from the sun, the Antarctic receives the minimum.
3. When summer begins on or about June 21 in the Arctic, winter begins on or about the same date (June 21) in the Antarctic.
4. The Arctic and Antarctic have opposite seasons.

Help the class make a colored picture record similar to Fig. 27.2. This record should be made on both sides of the paper, because the globe may have been viewed by the pupils from either side. Be sure the children agree that their picture record represents what they have seen and learned. Put this picture vertically in some kind of base so it can be left standing in the orbit at approximately the June 21 position. Use it when necessary for reviewing and comparing what the children learn later.

Fig. 27.2 A sample of a "colored" record of the earth's position in its orbit on or about June 21 (see text; both sides of the paper are shown here). The black area would be colored black and the white area would be colored yellow.



6. Where in its orbit is the earth located on or about December 21? What season begins on or about December 21 in the Arctic? In the Antarctic?

Ask the children to continue to orbit the globe until they find the position where winter begins for the Arctic clay figure (see Fig. 27.3). Darken the room and use the light. Help the pupils to discover that:

1. They moved the globe halfway around the orbit.
2. The North Pole is inclined at a maximum away from the sun and the South Pole at a maximum toward the sun.
3. The Arctic region receives the minimum number of hours of heat and light energy from the sun; the Antarctic, the maximum.
4. On or about December 21, winter begins in the Arctic and summer begins in the Antarctic.
5. The two polar regions have opposite seasons.

Have the class make another colored picture record similar to Fig. 27.2 to record what they have seen and learned about the earth in this location in its orbit (on or about December 21). Stand the picture at this place in the orbit for future review and comparison.

7. Where in its orbit is the earth on or about March 21 and on or about September 21? What seasons begin on or about March 21 and on or about September 21 in the Arctic? In the Antarctic?

Examine the spring and autumn positions of the earth with the projector light. First, place the globe in its approximate March 21 position in the orbit. Be sure that the North Pole points to the North Star. Spin the globe through one rotation. Compare the length of day and night for both the Arctic and Antarctic regions. When the globe is located in its March 21 position, make certain the children notice that:

1. Both the North and South Poles are tilted neither toward nor away from the sun;
2. Days and nights are equal in length;
3. Spring begins in the Arctic and autumn in the Antarctic;
4. The two polar regions have opposite seasons.

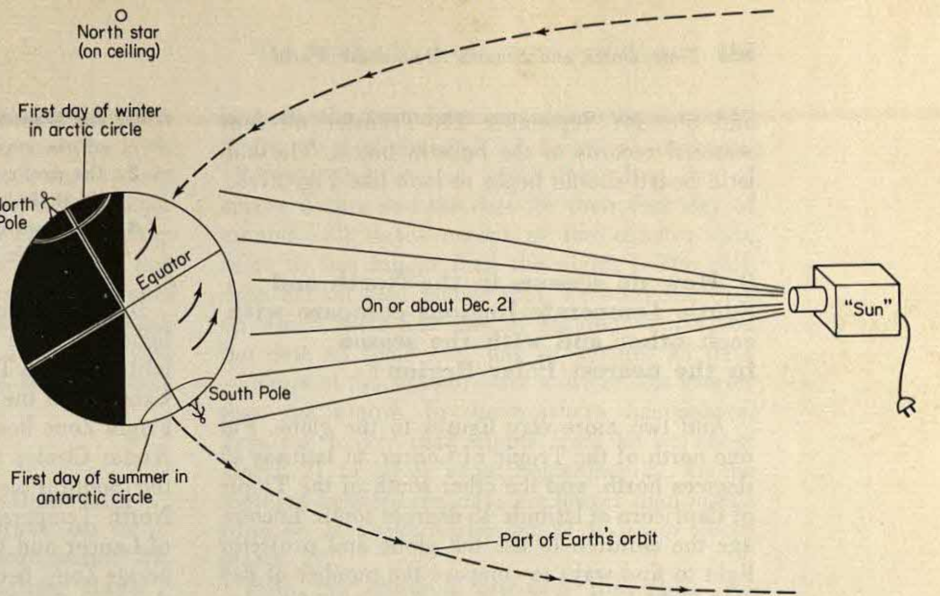


Fig. 27.3 Position of the earth in its orbit on or about December 21.

Finally, place the globe in the September 21 position in the orbit. Be sure the North Pole points to the North Star. Repeat the directions above. Have the children find the only two words in the four observations about the March 21 position that must be changed in order to make the same observations about the September 21 position. To what should they be changed?

Have the children draw two more picture records similar to Fig. 27.2—one for March 21

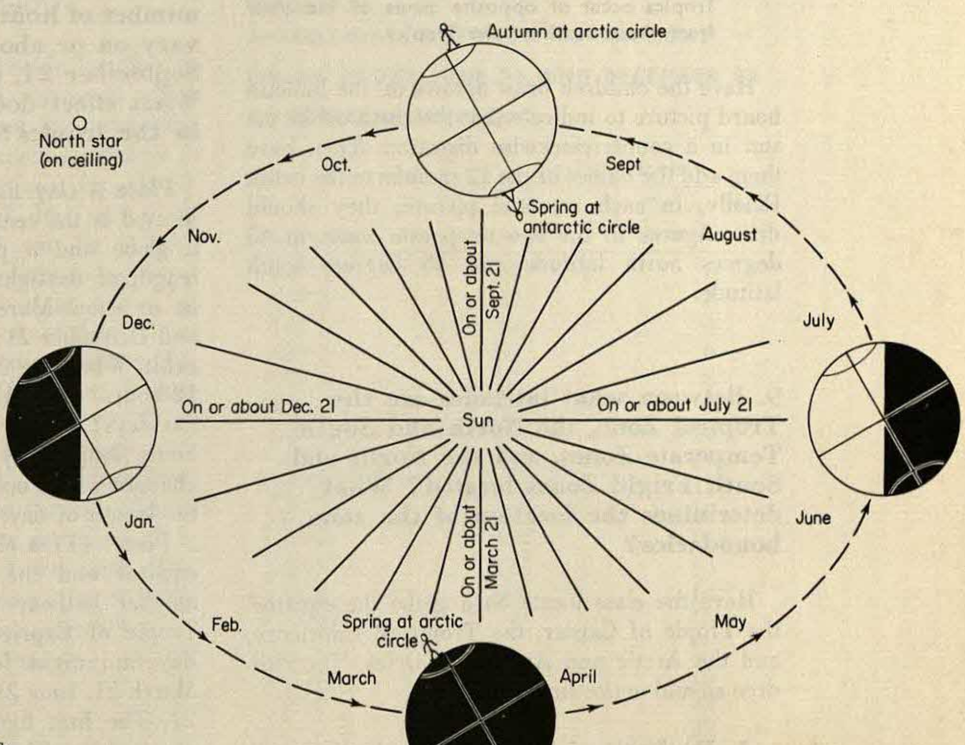


Fig. 27.4 A bulletin board display showing the position of the earth in its orbit at the beginning of each season of the year.

and one for September 21. Transfer all four seasonal records to the bulletin board. The bulletin board should begin to look like Fig. 27.4.

8. How do seasons in the North and South Temperate Regions compare with each other and with the season in the nearest Polar Region?

Add two more clay figures to the globe. Put one north of the Tropic of Cancer, at latitude 45 degrees north, and the other south of the Tropic of Capricorn at latitude 45 degrees south. Encourage the children to use the globe and projector light to find ways to compare the number of day and night hours for each figure on the first day of each of its four seasons. The children should be able to see and list these facts:

1. **The North Temperate Region and the Arctic have the same season at the same time.**
2. **The South Temperate Region and the Antarctic have the same season at the same time.**
3. **The four seasons in regions north of the Tropics occur at opposite times of the year from those south of the Tropics.**

Have the children draw arrows on the bulletin board picture to indicate that the earth orbits the sun in a counterclockwise direction. Then have them add the names of the 12 months to the orbit. Finally, in each seasonal picture, they should draw figures in the two temperate zones at 45 degrees north latitude and 45 degrees south latitude.

9. Between what latitudes are the Tropical Zone, the North and South Temperate Zones, and the North and South Frigid Zones located? What determines the location of the zone boundaries?

Have the class locate on a globe the equator, the Tropic of Cancer, the Tropic of Capricorn, and the Arctic and Antarctic Circles. The children should notice that:

1. **The Tropic of Cancer is 23 $\frac{1}{2}$ degrees north of the equator.**
2. **The Tropic of Capricorn is 23 $\frac{1}{2}$ degrees south of the equator.**
3. **The Arctic Circle is 23 $\frac{1}{2}$ degrees south of the North Pole.**
4. **The Antarctic Circle is 23 $\frac{1}{2}$ degrees north of the South Pole.**

It will be natural for pupils to assume that zone boundaries are determined by these four named latitudes. The Tropics are between the Tropic of Cancer and the Tropic of Capricorn. The North Frigid Zone lies between the North Pole and the Arctic Circle; the South Frigid Zone, between the South Pole and the Antarctic Circle. The North Temperate Zone lies between the Tropic of Cancer and the Arctic Circle; the South Temperate Zone, between the Tropic of Capricorn and the Antarctic Circle.

When the children have obtained this information, some of them will be able to deduce that these boundaries are determined by the number of degrees (23½) that the earth is inclined or tilted on its axis.

10. In the Tropical Zone, how do the number of hours of daylight and darkness vary on or about March 21, June 21, September 21, and December 21? What effect does this have on seasons in the tropics?

Place a clay figure on the equator, which is located at the center of the Tropical Zone. With a globe and a projector light, determine the length of daylight and darkness at the equator on or about March 21, June 21, September 21, and December 21; and at any other point in the orbit. When are days at the equator longer than 12 hours? (Never.) When are nights longer than the days? (Never, days and nights are each 12 hours long every day of the year.) Are any changes which occur at the equator the result of the length of days and nights? (No.)

Place: (1) a clay figure halfway between the equator and the Tropic of Cancer, and (2) another halfway between the equator and the Tropic of Capricorn. Determine the length of day and night for these figures on or about March 21, June 21, September 21, and December 21. The first figure has its longest day on or about June 21 and its shortest on or about December 21. On or about March 21 and September 21, its day and night are each 12 hours long. For the second figure, the longest day is on or about December 21; the shortest, on or about June 21. On or about March 21 and September 21, its days and nights are each 12 hours long. Why do not the variations in the length of day and night in these latitudes cause greater temperature changes? (The variations in the length of the day are too small to cause extreme changes.) How could the change be described? (Very hot to less hot.)

11. How many hours of daylight and darkness does your region have on or about March 21, June 21, September 21, and December 21? What regions have the greatest difference in the length of day and night? What regions have the least difference in the length of day and night? Between what dates are the days longer than the nights for your region? Between what dates are the nights longer than the days for your region? What causes the length of day and night to change?

Place a clay figure at the specific location on the globe which represents the region in which the children live. The technique for comparing the length of daylight and darkness (Inquiries 7, 8, 9, and 10) and the technique for closely approximating the number of day and night hours (Chap. 26, Inquiry 5) can be helpful. Have the children use these techniques to determine the number of day and night hours for their location at the previously established orbital positions of the earth on or about March 21, June 21, September 21, and December 21 (see Inquiries 7, 8, and 9).

For these same dates, have the children compare the number of day and night hours for their location with the number for other zones in the same hemisphere. Where on the earth is the difference in the length of day and night greatest? (The difference increases as the distance from the equator increases; the difference decreases as the distance from the equator decreases.)

Help the pupils use the globe and projector light to see and understand how the number of hours of daylight, except at the equator, change between the two dates on which there are 12 hours of daylight and 12 hours of darkness. (Between the date on which their first day of spring occurs and the date for their first day of autumn, all days—except at the equator—are more or less longer than the nights.) The children should also realize that, between the date on which their first day of autumn occurs and the date of their first day of spring, all days—except at the equator—are more or less shorter than the nights. In the northern hemisphere, days are longer than nights from on or about March 21 to on or about September 21. In the southern hemisphere, days are longer than nights from on or about September 21 to on or about March 21.

Help the children associate the cause for change in the length of day and night with (1) the inclination of the earth on its axis, and (2) the earth's revolution around the sun. First, adjust the axis of the globe to a perpendicular position. Spin the globe and orbit it around the make-believe sun. Be sure the children observe

Table 27.1

APPROXIMATE DURATION OF DAYLIGHT ON OR ABOUT JUNE 21 AND DECEMBER 21 AT DIFFERENT LATITUDES

	Daylight Hours	
Latitude	On or about June 21	On or about December 21
90° N	24	0
80° N	22	2
70° N	20	4
60° N	18	6
50° N	16	8
40° N	15	9
30° N	14	10
20° N	13	11
10° N	12½	11½
0°	12	12
10° S	11½	12½
20° S	11	13
30° S	10	14
40° S	9	15
50° S	8	16
60° S	6	18
70° S	4	20
80° S	2	22
90° S	0	24

that the days and nights *everywhere* on the globe are *always* equally long. Finally, change the axis of the globe to its correct inclination (23½ degrees from the perpendicular). *Station* the globe, with its North Pole *pointing* to the North Star, *at any one place* in the orbit. Spin the globe *but do not revolve it.* Make certain the children observe that any difference there may be between the length of the day and night *will not change* unless the globe moves in an orbit.

To help the children develop the understanding that there are *daily variations* in the length of day and night, have them for a few weeks keep a daily record of the time the sun rises and sets. On clear days, some children may wish to observe and record the exact time of sunset. Many newspapers, radio stations, and television stations include in their daily weather report the local time for sunrise and sunset. See Table 27.1 for approximate variation of daylight at different latitudes. Make a chart of questions like the one in Table 27.2 and have the pupils use their bulletin board pictures (see Fig. 27.4) to answer the questions.

Ask the class to write "Dear Friend Letters" to children who live in large cities located on the opposite side of the equator from them. In these letters, they might include their ages and describe the seasonal things they are doing and the seasonal clothing that they are wearing. They might also suggest that they would appreciate letters from these children describing their sea-

Table 27.2

FACTS ABOUT THE FOUR SEASONS OF THE NORTHERN AND SOUTHERN HEMISPHERES

Questions	Northern Hemisphere (Dates, on or about)	Southern Hemisphere (Dates, on or about)
1. When is the *longest day?*	June 21	December 21
2. How many hours did you count for *your longest day?*	Varies with latitude	Varies with latitude
3. When is the *shortest day?*	December 21	June 21
4. How many hours did you count for *your shortest day?*	Varies with latitude	Varies with latitude
5. When are days and nights the same length?	March 21 and Sept. 21	Sept. 21 and March 21
6. Between what dates are the *days longer than the nights?*	March 21 to Sept. 21	Sept. 21 to March 21
7. Between what dates are the *days shorter than the nights?*	Sept. 21 to March 21	March 21 to Sept. 21
8. Between what dates are the days *increasing in length?*	Dec. 21 to June 21	June 21 to Dec. 21
9. Between what dates are the days *decreasing in length?*	June 21 to Dec. 21	Dec. 21 to June 21
10. What date is the *first day of summer?*	June 21	December 21
11. What date is the *first day of autumn?*	September 21	March 21
12. Between what dates does the *summer season occur?*	June 21 to Sept. 21	Dec. 21 to March 21
13. What is the *first day of winter?*	December 21	June 21
14. Between what dates does the *autumn season occur?*	Sept. 21 to Dec. 21	March 21 to June 21
15. What is the *first day of spring?*	March 21	September 21
16. Between what dates does the *winter season occur?*	Dec. 21 to March 21	June 21 to Sept. 21
17. Between what dates does the *spring season occur?*	March 21 to June 21	Sept. 21 to Dec. 21

sonal activities and clothing for the same month of the year. If these letters are sent addressed to the [Fifth] Grade, Public Schools of the city and country of their choice, many of them will be delivered and some answers will be received. If this does not seem feasible, let some of the pupils in your classroom pretend that they live in these countries and answer the letters. However, mailing and receiving answers can be a very much more exciting experience.

12. What is the difference between direct and indirect or slanting light rays? What can we use to observe this difference?

Stand a tiny doll on a large piece of white paper. Darken the room. Ask a child to hold a flashlight above the doll so that the light shines *directly* down on the doll's head. Ask another child to trace the doll's shadow on the paper. (It will be a very small area around the doll's feet.) Hold the flashlight at the same height, but move it about one foot to the side so its light shines on the doll *indirectly* or at a *slant.* Trace the shadow. (The shadow will be larger, longer, and on the opposite side of the doll from the flashlight.) Have different children hold the flashlight at different angles and observe how the shadow changes. Apply these experiences to shadows caused by sunlight. Give the children an opportunity to go outdoors three times on the same day to observe their shadows. They should compare their own morning, noon, and afternoon shadows. Help them to make statements similar to these: When the sun is directly overhead, our area receives *direct rays.* Direct rays cause the very smallest shadows. When the sun is not directly overhead, the sun's rays strike our area *indirectly* or on a *slant.* The more the rays slant, the longer the shadows are.

Observations like these with the changing lengths of shadows will help children to find out whether their area *ever receives direct rays.* Such observations will also help them to determine the *date* and *time* that their area has its shortest shadows.

Use a pencil sundial like the one suggested in Chap. 26, Inquiry 1. Have the class make hourly records of the pencil's shadow to discover the *time* of day its shadow is the shortest. (This will be the time of day when the sun shines directly or almost directly from overhead. This is noon *solar time.* It *may not be* 12 noon by the clock.)

Repeat this experience on or near the first day of the month for three or four months. Compare the length of the shadows cast at noon solar time. (In the northern or southern hemisphere, the shadows *will increase in length* from the first day of *summer* to the first day of *winter* and *decrease* in length from the first day of *winter* to the first day of *summer.*)

13. Why do direct rays from the sun warm an area more than indirect or slanting rays?

Shine a flashlight directly on a piece of white paper. Ask one child to trace around the spot of light the flashlight makes on the paper, and another to measure the distance from the flashlight lens to the paper. Turn the flashlight so that its light will strike the paper at a slant or indirectly. Be sure it is held the same distance from the paper. Trace this spot of light. Compare the sizes of the two spots. Ask the children why the *same amount* of light from the flashlight causes spots of different sizes. (The size of the area touched by the light rays of the flashlight depends on the angle at which the rays hit the paper. Apply this experience to direct and indirect rays of sunlight striking the surface of the earth. Have them explain why the sun's rays feel warmer when they strike a smaller area. (Because the sun's rays are concentrated in a smaller area, they make the area warmer.) If necessary, review the experience (Inquiry 1) in which the children discovered that some things can be burned or melted by using a magnifying glass to concentrate the heat from sunlight into a small area.

Reinforce this understanding by asking the children to do this experiment, and use a thermometer to compare the results. Place some soil in a covered container and cool it below room temperature. Also, cool two matching pans, a tablespoon, and a measuring cup. After cooling, stir the soil until its temperature is the same throughout the container. Place equal amounts of soil in each pan. Label pan number one "Heated by Direct Rays from the Sun" and pan number two "Heated by Indirect Rays from the Sun." Insert a toothpick into the soil in each pan to help the children determine the angle at which the pans must be placed in the sunlight. (By tilting the pans, the size of the shadows cast by the toothpicks can be controlled to simulate the very small base shadow cast by nearly direct rays and the longer shadow, by indirect rays. Support both pans on good insulators such as books or blocks of wood so that air is free to flow under each pan.) Encourage the children to predict which pan will gain more heat. (Pan number one.) Measure and record the temperature of the soil in each pan at ten-minute intervals, until a difference in temperature is noted.

14. Where do the sun's rays strike the earth directly? When do they strike these areas directly? What parts of the earth receive only indirect or slanting rays from the sun? When do slanting rays strike these areas with less slant? More slant?

Set up the globe and a projector as shown in Fig. 27.3. Place a tiny clay figure (1) in the Arctic Circle, (2) at 45 degrees north latitude, (3) on the Tropic of Cancer, (4) on the equator, (5) on the Tropic of Capricorn, (6) at 45 degrees south latitude, and (7) in the Antarctic Circle. Place the globe in the on or about March 21 position in its orbit and rotate it so that it will be noon for all of the clay figures. The globe may need to be rotated a little past the noon position in order to separate the shadows of the seven figures. Compare the shadows of the figures. Which figure casts the smallest shadow? What does this show? (The figure at the equator casts the smallest shadow. This region is receiving direct rays of light.) Where are the sun's rays striking the globe at a slant or indirectly? (All other regions are receiving indirect or slanting rays of light.) Call attention to the differences in the sizes of the shadows cast by the clay figures. Which shadows are the longest? Where are the middle-sized shadows? (In the Arctic and Antarctic Circles. At 45 degrees north and south latitudes.) What do these differences in the sizes of the shadows tell us about the rays of light? (The farther a region is from the equator, the more slanted or indirect are the rays of light that it receives.) What part of the world would receive the most concentrated infrared rays on or about March 21? (The equator.) What would the temperature at the equator be like on or about March 21? (Very hot.)

Move the globe to the on or about June 21 position. Rotate the globe so that the figures are at the noon or a near noon position. Which figure is receiving direct rays? (The figure at the Tropic of Cancer.) What kind of rays are the other figures receiving? (Indirect or slanting rays.) Compare the size of the shadow cast by the clay figure at 45 degrees north latitude with the one at 45 degrees south latitude. Which place would be warmer? (Forty-five degrees north latitude would be warmer because its smaller shadow indicates that it is receiving rays that are more nearly direct.) Observe that the shadow cast by the clay figure at the equator is slightly larger than it was in the on or about March 21 position. What change in temperature would you expect? (It would be slightly cooler.) Notice the shadow of the figure in the Arctic. Its shadow is the largest of all. Where would it be colder, in the Arctic or the Antarctic? (In the Antarctic because it is not receiving any sunlight.)

Move the globe to the on or about September 21 position and center the figures at or near noon. Now, where are the sun's rays shining directly? (On the equator.) What would the temperature at the equator be like? (Very hot.) On what other date did the equator receive direct rays from the sun? (On or about March 21.) What kind of rays are being received by all the other figures? (Slanting rays.)

Set up the globe in the on or about December 21 position. Where, at noon, are the rays direct? (At the Tropic of Capricorn.) Why is it summer at 45 degrees south latitude and winter at 45 degrees north latitude? (The rays at 45 degrees south latitude are not nearly so slanting as they are at 45 degrees north latitude.) Compare the figures in the Arctic and Antarctic Circles. Which one is having summer? (The one in the Antarctic, because it is receiving some heat from the very slanting infrared rays of the sun. For a part of this season the Antarctic receives 24 hours of sunlight daily.) Why is it winter in the Arctic? (Because this region receives no sunlight at all during a part of the winter season; the sunlight does gradually increase as the season progresses, however.)

Observe the shadow cast by the clay figure at the equator. On what other date did the equator receive indirect rays of sunlight? (On or about June 21.) What change in temperature would you expect? (It would be cooler.)

15. Why does the amount of slant of the sun's rays vary with the time of day? Why does the amount of slant of the sun's rays vary with the position of the earth in its orbit? Why does the amount of slant with which the sun's rays reach the earth vary with different latitudes on the earth? Why do the seasons change with changes in the angle at which the rays are received?

Slowly spin the globe with the seven clay figures on it. (See Inquiry 14.) Ask the children to observe when the shadows cast by the figures are the smallest. (They are smallest at noon.) Repeat the procedure several times to find out whether their observations will be the same. (They should be.) When are the shadows the longest? (Immediately after sunrise and before sunset.) Review Chap. 26, Inquiry 1.

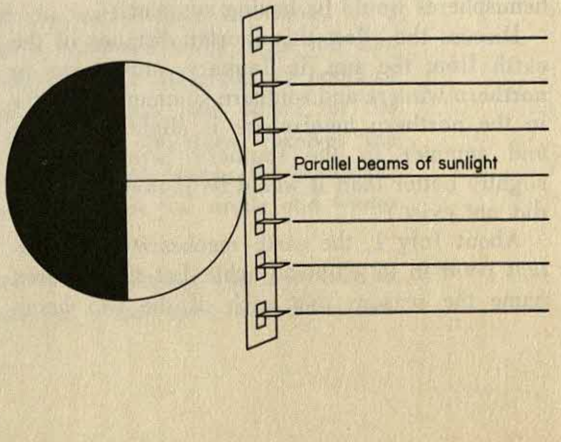
Help the class associate the spinning or rotation of the earth with the change in slant or directness in which the rays are received. As the earth turns toward the noon position, the rays become more and more nearly direct.

The revolution of the earth causes direct rays at noon in certain areas on certain dates. (See Inquiry 14.) As the earth's axis inclines away from the sun, the noon rays become less and less direct.

Review Inquiry 9 for zones and zone boundaries. Help the pupils formulate statements similar to these. On or about June 21, the first day of summer in the northern hemisphere, the North Pole has its maximum tilt (23½ degrees) *toward the sun*, the Tropic of Cancer (23½ degrees north of the equator) receives direct rays from the sun, and all zones north of the Tropic of Cancer are receiving their most nearly direct rays of the year. On or about December 21, the first day of summer in the southern hemisphere, the South Pole has its maximum tilt (23½ degrees) *toward the sun*, the Tropic of Capricorn (23½ degrees south of the equator) receives direct rays from the sun, and all zones south of the Tropic of Capricorn are receiving their most nearly direct rays of the year. On or about March 21 and September 21, when both poles tilt neither toward nor away from the sun, the equator receives direct rays from the sun. These are the two hottest times of the years at the equator. On or about June 21 and December 21, it is a little cooler at the equator.

Give the class the opportunity to explain why they think the sun's rays do not strike all areas of the earth directly. They may need further experiences to help them visualize that the earth's curvature or shape is the cause. Have the children feel the curvature of the globe. Cut a strip of stiff paper one inch wide and long enough to follow the curvature of the globe from one pole to the other. Hold or tape the strip to one meridian on the globe while the children attach shadow markers at the seven locations previously used in Inquiry 14. Markers can be made by cutting seven very thin strips one inch long from the gummed edge of an envelope flap. Fold them in the middle and then fold a little of each end outward to form a base. Wet, press together the upper part and then press the two "feet" to the stiff paper strip. When the seven shadow makers are all in place, remove the strip from the globe. Hold it without any curvature in front of the globe touching the globe only at the equator. (See Fig. 27.5.) Darken the room. Turn on the projector light. Examine the seven shadows. Do they indicate direct or indirect rays? (Direct.) Curve the strip and reattach it to the globe. (See Fig. 27.6.) How do the shadows change? How

Fig. 27.5 Shadows at every latitude would all be the same length on an earth without a curved surface.



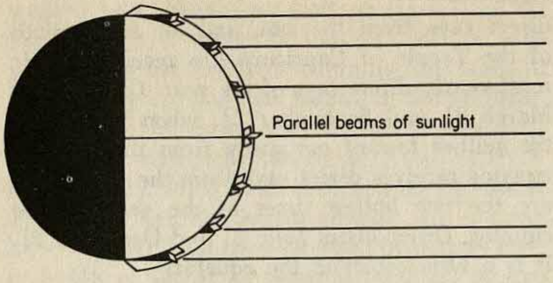


Fig. 27.6 Curvature of earth causes length of shadows to vary with latitude.

does the curvature of the globe change the way in which the light rays are received? (Most shadows are now longer. The rays strike only one marker from overhead (directly). The rest receive the rays indirectly as indicated by the longer shadows.)

16. What effect does the elliptical shape of the earth's orbit have on the seasons?

Have the children find out whether the earth is always the same distance from the sun. (It is not. Its orbit is an ellipse.) Review the experiences in Chap. 25, Inquiry 1, in which the difference between a circle and an ellipse is developed. Also, have the class locate information regarding *when* the earth is nearest to the sun and *how much nearer* it is. (The earth is about three million miles closer to the sun a few days after January 1 than it is at any other month. Help the pupils recall that in January, the northern hemisphere is having its winter season and the southern hemisphere its summer season. Ask the class what season each of the hemispheres would be having in January, *if the seasons were caused by differences* in the distances of the earth from the sun. (Both northern and southern hemispheres would be having summer.)

Discuss the effect this shorter distance of the earth from the sun, in January, must have on northern winters and southern summers. (Winter in the northern hemisphere is slightly warmer and summer in the southern hemisphere is slightly hotter than it would be if this difference did not exist.)

About July 1, the earth reaches *its most distant point* in its elliptical orbit. Let the children name the seasons that each of the two hemispheres is having and discuss what effects they think this greater distance might have. (The summer season in the northern hemisphere and the winter season in the southern hemisphere are slightly colder than they would be if this difference did not exist.)

17. What causes seasonal changes?

Help the children summarize what they have learned in the preceding inquiries about seasonal change by using questions similar to these. If necessary, use the globe and filmstrip projector to help them visualize the conditions implied by the questions.

A. What Would Be the Result If the Earth's Axis Was Perpendicular? Every day of the year and everywhere on the earth, days and nights would be 12 hours long. The temperature in the tropics would be higher and temperatures in regions lying beyond the tropic would be more moderate than they now are. Different areas would have different climates. However, in any one area there would be a sameness to the climate, year in and year out. Plant, animal, and population distribution would be different. Encourage the children to use their imagination and make guesses as to the changes in their region that might result if days and nights were always 12 hours long.

B. What Would Be the Result If the Earth's North Pole Always Tilted Toward the Sun? At any given place on the earth, the number of hours of daylight and darkness would not change. The northern hemisphere would always have longer days than nights and higher temperatures. The southern hemisphere would always have longer nights than days and be much colder all year. Because the northern hemisphere would always absorb more heat during the daytime than it lost at night, it would become progressively warmer. It might even become tropical. Because the southern hemisphere would lose more heat than it absorbed during the daytime, it could become progressively colder. An ice age could result.

C. What Would Be the Result If the Earth's South Pole Always Tilted Toward the Sun? The reverse of the conditions listed in question "B" might result.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Light rays are visible rays. Sunlight is a mixture of different colored light rays. The colors that compose sunlight are called the visible spectrum. Many rays given off by the sun are invisible. "Heat rays," or infrared rays, are one kind of invisible ray. Materials that absorb light rays and infrared rays get warm. Materials that do not absorb these rays, such as window glass, stay cool. Some materials that absorb light rays and infrared rays, which have been concentrated or focused by a magnifying lens, can become hot enough to burn or melt.

Light rays make it possible for us to see things. Some things on the earth are made to produce radiant heat and light. Rays travel from the radiant object to the object that receives them. The radiant object does not need to touch an object in order to light and heat it.

2. An earth year is a measure of the time it takes the earth to make one orbit around the sun. The length of a year on the eight other known planets in the solar system depends on the time it takes them to orbit the sun. Planets that are nearer the sun than the earth orbit the sun in less time and have shorter years. Planets that are farther from the sun require more time and have longer years.

A year is divided into 12 calendar months, 365 $\frac{1}{4}$ days, 52 weeks, and in the temperate and frigid zones into four seasons. A leap year occurs every fourth year and contains one more calendar day than the three previous years.

3. The earth is inclined or tilted on its axis. The north pole of the earth's axis always points toward the North Star. In the course of one orbit, the north pole of the earth's axis points (1) toward the sun, (2) neither toward nor away from the sun, (3) away from the sun, and (4) neither toward nor away from the sun. The direction reaches its maximum change at four places in the orbit. These four locations divide the orbit into four quarters. Each quarter section of the orbit is associated with one season in the temperate and frigid zones.

4. The summer and winter seasons of the year for temperate and polar regions differ in the amount and intensity of the heat and light energy they receive from the sun. In these regions, the spring and autumn seasons receive the same amount and intensity of the heat and light energy from the sun. The differences between spring and autumn are caused by the season that precedes them.

5. On or about June 21, the north pole of the earth's axis is inclined at a maximum toward the sun; the south pole, at a maximum away from the sun. This causes the Arctic to have 24 hours of daylight; the Antarctic, 24 hours of darkness. On or about June 21, the longest day of the year occurs for the Arctic and the shortest for the Antarctic. The Arctic, therefore, receives the sun's heat and light energy for the maximum number of hours; the Antarctic, the minimum. On or about June 21, summer begins in the Arctic and winter begins in the Antarctic.

6. On or about December 21, the north pole of the earth's axis is inclined at a maximum away from the sun; the south pole, at a maximum toward the sun.

This causes the Arctic to have 24 hours of darkness; the Antarctic, 24 hours of daylight. On or about December 21, the shortest day of the year occurs for the Arctic; the longest for the Antarctic. The Arctic, therefore, receives the sun's heat and light energy for the minimum number of hours; the Antarctic for the maximum number of hours. On or about December 21, winter begins in the Arctic; summer in the Antarctic.

7. On or about March 21, the earth is halfway in its orbit between the on or about December 21 and June 21 positions; on or about September 21, halfway between June 21 and December 21. On or about March 21 and September 21, both the north and south poles of the earth's axis are inclined neither toward nor away from the sun. On both dates, this causes both the Arctic and Antarctic regions to have 12 hours of daylight and 12 hours of darkness. On or about March 21, the first day of spring occurs in the Arctic; the first day of autumn in the Antarctic. On or about September 21, the first day of autumn in the Arctic and the first day of spring in the Antarctic begins.

8. The seasons—summer, winter, spring, and autumn—occur at the same time of year in the North Temperate Region and in the Arctic. The four seasons also occur at the same time of year in the South Temperate Region and in the Antarctic. The four seasons in regions north of the Tropics occur at opposite times of the year from those south of the Tropics.

9. The earth is divided into one tropical, two temperate, and two frigid zones. Their boundaries are determined by the $23\frac{1}{2}$ degrees at which the earth's axis is inclined. The boundaries occur at the Arctic Circle, the Tropic of Cancer, the Tropic of Capricorn, and the Antarctic Circle. These boundaries are either $23\frac{1}{2}$ degrees from the equator or $23\frac{1}{2}$ degrees from one of the poles.

10. Daylight and darkness at the equator are 12 hours long every day of the year. Therefore, any changes which may occur at the equator are not caused by changes in the length of daylight and darkness.

At all other locations within the Tropical Zone, the changes in the number of hours of daylight and darkness are very small. In temperature, the Tropical Zone varies from very hot to less hot.

11. Except at the equator, from day to day the number of hours of daylight and darkness in any 24-hour period varies from one latitude to another. The difference between the length of day and night increases as the distance from the equator increases; and decreases as the distance from the equator decreases. In the northern hemisphere, days are longer than nights from on or about March 21 to September 21; and nights are longer than days from on or about September 21 to March 21. In the southern hemisphere, days are longer than nights from on or about September 21 to March 21; and nights are longer than days from on or about March 21 to September 21. The length of day and night changes because the earth is a sphere, the earth is inclined on its axis $23\frac{1}{2}$ degrees from the perpendicular, and because the earth orbits the sun.

12. Direct rays shine from directly overhead. Rays that do not shine from directly overhead are called indirect or slanting rays. Direct rays cause very small shadows. Slanting rays cause longer shadows. The more indirect or slanting the rays are, the longer are the shadows that they cause.

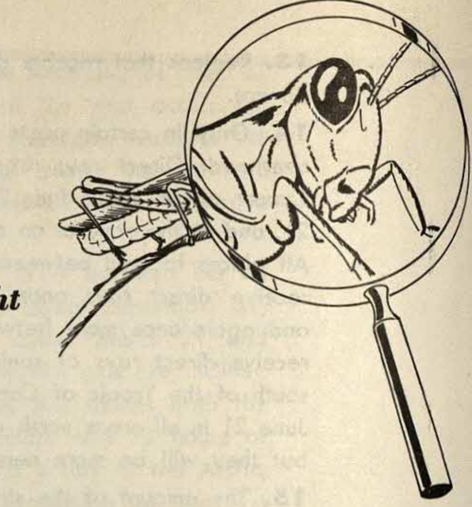
13. Regions that receive direct rays of sunlight are warmer than regions that do not.

14. Only in certain parts of the world, at noon, are the sun's rays ever directly overhead. Direct rays from the sun are received at noon on the Tropic of Cancer on or about June 21, at the Tropic of Capricorn on or about December 21, and at the equator on or about March 21 and on or about September 21. All places located between the Tropic of Cancer and the Tropic of Capricorn receive direct rays once between on or about June 21 and December 21, and again once more between December 21 and June 21. Many areas never receive direct rays of sunlight. All areas north of the Tropic of Cancer and south of the Tropic of Capricorn receive only slanting rays. At noon on or about June 21 in all areas north of the Tropic of Cancer, the sun's rays are slanting but they will be more nearly overhead than on any other day of the year.

15. The amount of the slant of the sun's rays varies: (1) with the time of day, because of the earth's rotation on its axis; (2) with the position of the earth in its orbit, because of the way in which the inclination of the earth's axis changes with respect to the sun during each revolution; and (3) in different latitudes, because of the curvature of the earth's surface. The seasons change with the different degrees of slant with which the sun's rays strike a region, because the amount of heat received by an area is proportional to the angle of slant.

16. The elliptical shape of the earth's orbit causes variations in the earth's distance from the sun. The earth is nearest the sun in January and farthest from the sun in July. Changes in seasons are not caused by changes in the earth's distance from the sun. The elliptical shape of the earth's orbit does effect seasonal temperatures. Because the earth is closest to the sun in January, both hemispheres have slightly warmer weather. The earth's greater distance from the sun in July causes both hemispheres to have slightly cooler weather.

17. Seasonal changes are a result of changes in the amount of sunlight received. Changes in the amount of sunlight received are caused by these factors: (1) the earth's shape; (2) the earth's rotation; (3) the earth's revolution; and (4) the inclination of the North Pole the earth's axis toward the North Star.



Chapter Twenty-Eight

Light and Vision

Reflection, Transmission, and Absorption of Light

INQUIRIES

1. What do we need in order to see?

2. How can we find out whether light from objects in the classroom travels in a straight line?

3. What do mirrors do to light? What other materials reflect light almost as well as mirrors? What kinds of things make the best reflectors?

4. Why can we see an image of ourselves in a reflector? Why can we see an image of another person in a mirror? How are reflectors used?

5. How do we see most objects?

6. What things seem to give off light? Which ones produce light? Which reflect light?

7. What is the earth's most important source of light? Why is sunlight both a direct and indirect source of natural and artificial light?

8. What is the difference between luminous and nonluminous objects? Why can we see nonluminous objects?

9. How do different materials affect the transmission of light? What are good and poor transmitters of light called?

10. Why do some surfaces look dull and others shiny? What is the light which is reflected from smooth shiny surfaces called? From rough dull surfaces?

11. Which surfaces, smooth or rough, make better reflectors? Which surfaces absorb more light, smooth or rough ones? Why do rough dull surfaces absorb more light than smooth shiny ones? Why do rough dull surfaces make poorer image reflectors than smooth shiny ones?

1. What do we need in order to see?

Have the children name some of the objects they can see around them (indoors and outdoors). Then ask them to close their eyes and tell whether they can still see these objects. (To see things we must use our eyes.)

Let small groups of children take turns going into a very dark closet to discover whether they can see and identify objects in the dark. (There must be light in order to see things.)

Help the children to understand that even *when they use their eyes* and when *there is enough light to see* by that there also must be a visible object. They should, also, realize that an object cannot be seen when *any one* of the three factors is missing.

2. How can we find out whether light from objects in the classroom travels in a straight line?

Try these experiences to find out how light travels. Then, encourage the pupils to think of other experiments they can do.

Obtain a piece of garden hose that is at least two feet long. Lay a yardstick on a table. Ask two pupils to hold the hose so that it is parallel with the yardstick. Ask another pupil to hold a flashlight so that its light shines into one end of the hose. Have each child in the room look into the other end of the hose. Results? (The light will be seen.)

Slowly bend the hose until the light from the flashlight cannot be seen shining through the hose. Have each pupil look into the unlighted end of the hose. When was the light from the flashlight seen? (When the hose was in a straight line.)

Hold the hose in a straight line so that it is pointed toward a window. Look through the end of the hose that is away from the window. Can the light which is coming through the window also be seen coming through the hose? (It can be seen.) Bend the hose. Point one end at the window. Results? (No direct light will be seen.) Place a pencil across one end of the hose. Hold the hose in a straight line. Can a portion of the pencil be seen? (Yes.) Bend the hose and look again. Results? (None of the pencil will be seen.) Repeat the same procedure with other small objects in the room. Conclusions?

3. What do mirrors do to light? What other materials reflect light almost as well as mirrors? What kinds of things make the best reflectors?

Ask each child to bring a small mirror to school. The mirrors from women's purses are excellent. At a time when sunlight floods into the room, raise all window shades and let the children play with their mirrors. When they have discovered that they can direct the sunlight into many areas of the room by changing the position of the mirror, place some pieces of white paper around the room as targets and ask the children to try hitting each target with light from their mirrors.

Encourage the children to invent other mirror games. The following games were developed by teachers who capitalized on things they observed young children doing in free experimental play.

1. *Observed:* One child with the light from his mirror trying to "catch" another child's spot of reflected light.
   Game: Mirror tag
2. *Observed:* Four children trying to line up the light reflected from their four mirrors along the top of the chalkboard.
   Game: Line up the "mirror light"
3. *Observed:* A child sending a series of flashes by interrupting with his hand the light beam from his mirror.
   Game: Add the flashes and flash the answer (Best played by three children. For example,

the first child sends 3 flashes, the second child sends 4 flashes, and the third child sends 7 flashes as the answer.)

4. **Observed: One child tracing the large printed letters on a bulletin board chart with the light beam from his mirror.**
Game: Guess the letter (One child "traces" an imaginary letter in light on a blank wall, chalkboard, or ceiling. Other children try to guess the letter.)

On a dark cloudy day tell the children that you had planned to have them do more experiments with their mirrors but there isn't enough sunlight. Encourage them to think of other light sources they could use instead of the weak light now entering the room. They may suggest ceiling lights, candle light, light from a flashlight, and light from the filmstrip projector. Anticipate their answers by having these things available. Further darken the room by closing off as much of the outside light as possible. Place the lighted candle in a safe place high above the reach of children. Let them test their mirrors in each of the available sources of artificial light.

When the mirrors have been put away, suggest to the group that it is time to decide what mirrors do to light. Ask the children to tell what they think the mirror does to light. Listen to their explanations and possible arguments for evidence of understandings. You may even hear them using the words "bounce" and "reflect." When their discussion indicates their *awareness* of the basic idea of reflection, help them to draw a diagram on the chalkboard similar to Fig. 28.1.

Emphasize the word "reflect" by using it and adding it and its variants to the diagram. When the children have finished their diagrams, encourage them to discuss what they have learned about mirrors in sentences, such as:

1. **A mirror *reflects* light.**
2. **A mirror is a *reflector*.**
3. ***Reflected light* leaves the mirror.**

Reinforce these learnings by placing a mirror on the floor, darkening the room, and having the children aim the beam from a flashlight at the mirror (see Fig. 28.1). Use some removable marker to indicate where the light reflected from the flashlight strikes the wall.

Have two children clap chalkboard erasers on either side of and over the mirror. The chalk dust will make the beam of light traveling to and from the mirror visible.

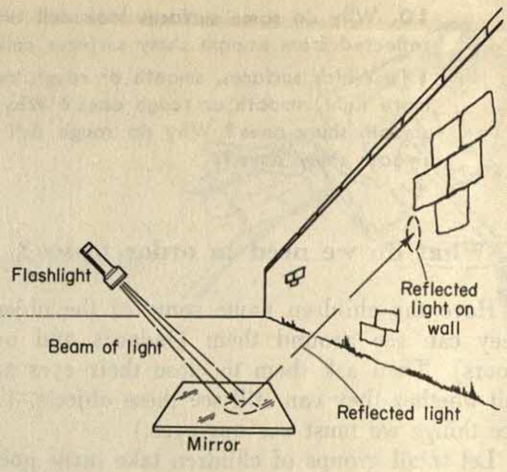


Fig. 28.1 A mirror reflects light.

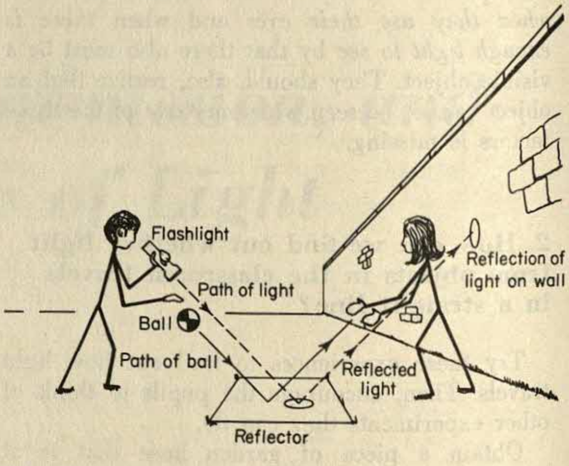


Fig. 28.2 Light bounces like a ball when it strikes the surface of a reflector.

If your mirror is made of glass, replace it with a metal reflector. Attach the lighted flashlight to a chair back or other firm support. Provide one of the small rubber balls children use when playing jacks. Ask the children to try to bounce the ball off the mirror so the ball will hit the spot of reflected light on the wall. They will soon discover that the ball follows the light's path (a straight line) when it is released from the hand near the same place the light leaves the flashlight (see Fig. 28.2).

Ask the children to look everywhere for *other* things that reflect light and if it is possible to bring them to school to show the class. Children have brought and demonstrated the ability of many things to reflect light. Some common ones are:

1. Aluminum foil
2. Glass
3. Knives and spoons
4. A pan of water
5. Stainless steel objects
6. Chromium plated objects

Encourage the children to examine all reflectors carefully to find out in what ways they are alike and to think about what causes some of them to be better reflectors than others. (They are smooth and shiny.)

4. Why can we see an image of ourselves in a reflector? Why can we see an image of another person in a mirror? How are reflectors used?

Have the children hold their mirrors in front of them. Ask them what they see. They will often say, "We see ourselves." Help them to realize that what they see is only an *image* of themselves. This experiment is fun to do. It also will help young children to develop the concept that what is seen in a mirror is an image. Try "walking up" to one *child's mirror* first and then to another's and *saying to the images* there in the mirror some of the following things:

1. Please comb your hair with this comb.
2. Shut your eyes.
3. Wink at me.
4. Blow your nose with this paper handkerchief.
5. This cold cream will help your freckles.

When the laughter is over, quickly line up the children one behind the other. Take them into some "windowless" room in the school, which is completely dark inside when the door is closed and the light is out. Before you close the door and turn out the light, ask them to hold up their mirror so they can see their image in it. Shut the door and just before you turn out the light, say, "Can you see your image in your mirror?" In the sudden darkness repeat, "Can you see your image now? Why not? What must be present for a reflector to form an image of an object?" (Light.)

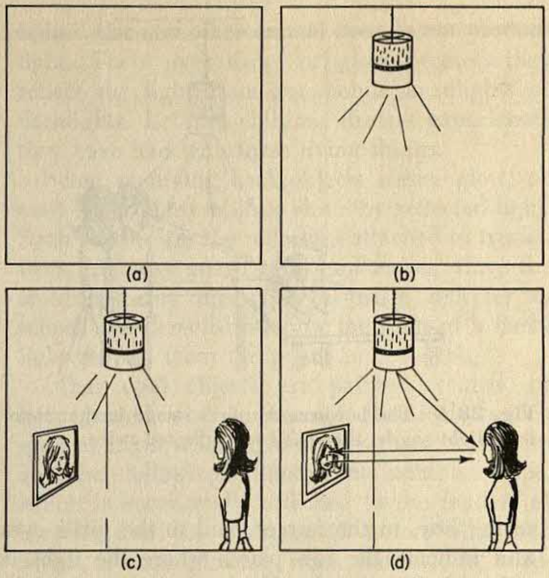


Fig. 28.3 A picture record. (a) "This is the room." (b) "This is the ceiling light in the room. It is turned on." (c) "Here you are with your reflector. See your image in it." (d) "Where shall we put arrows to show how the light goes from the light to you, from you to the mirror, and from the mirror back to your eyes?"

When you are back in the classroom, with the mirrors put away, draw a diagram like Fig. 28.3 on the chalkboard.

Ask the children for suggestions for tracing the path that the light must take to form (1) a person's image on the reflector, and (2) to carry the image to the person's eyes. They should finally decide that light (1) travels in a straight line from the light source to the person; (2) *reflects from the person* to the mirror where it produces the image; and (3) reflects from the mirror to the person's eyes. [See (d) in Fig. 28.3.] Add arrows to show this path and help them to understand that the light is reflected twice, once from the person to the mirror and again from the mirror back to the person's eyes.

Arrange a table, a mirror, and two children under a light, as shown in Figure 28.4. Be sure the class realizes that the boy sees the girl's image *because* the light shining on the girl is reflected to the mirror and forms her image, and finally, the light from her image is reflected from the mirror to the boy's eyes. The girl will see the boy's image at the same time. Have pupils trace the path of the light from the light source

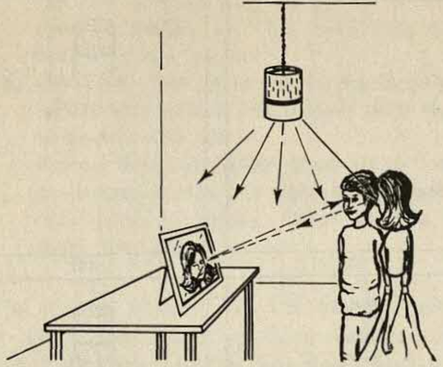


Fig. 28.4 The boy sees the girl's image in the mirror by a light source that has been reflected twice.

to the boy, to the mirror, and to the girl's eyes and indicate the two places where the light is reflected. Observe that light travels in a straight line from the girl to the mirror and from the mirrors to the boy.

Encourage the children to search for other interesting ways mirrors are used. They should find some of these ways: rear view mirrors in cars; outside mirrors near the front doors of some automobiles and all trucks; the mirror used inside a patient's mouth by a dentist; the mirrors in a periscope; a mirror at the intersection of a blind driveway and a busy highway to help the driver see if an opening in traffic will permit him to enter the highway safely; and mirrors in survival kits for wrecked sailors and aviators to attract the attention of rescue boats and planes, by reflecting flashes of sunlight to the rescue craft.

Except for the dentist's mirror, all the illustrations in the preceding paragraph for using mirrors can be "play acted" with the children's small mirrors. Let them show how it can be done. Help them to find a diagram of how two mirrors are placed in a periscope and ask some boys to build a periscope out of a cardboard mailing tube and two mirrors.

Have the children look in science books for other interesting things they can do with mirrors. Help them to carry out these activities and to use their knowledge of reflectors to explain how the new experience works.

Have the class draw pictures similar to the diagrams in Inquiries 2 and 3 to illustrate their experiences with reflectors. Ask them to put these pictures and any other graphic materials that tell the story of reflectors and reflected light on the bulletin board. Help the pupils make this display as attractive and original as possible.

5. How do we see most objects?

Ask each child to select a small object that he can carry. Return to the dark closet with the children. Review the experience that objects and people cannot be seen or identified in complete darkness. With the closet light "turned on" ask, "How does the light help you to see each other and the objects you hold?" (The light travels from the light to the object or person and is reflected from the object or person to our eyes.) "By what kind of light do you see each other and these objects?" (By reflected light.) "In this closet, what one object do you not see by reflected light?" (The closet light.)

6. What things seem to give off light? Which ones produce light? Which reflect light?

Have the pupils make a general list of as many things as they can that seem to give off light. Assist them in making a list as varied as this:

sun
lighted matches
lighted candles
moon
burning coal
lighted oil and gas lamps
some deep sea fish
radium
hands and dials of some clocks and watches
reflectors used on trucks and fences
space craft reentering earth's atmosphere
torch
comets
burning oil
burning gasoline
forest fires
incandescent lights
fluorescent lights
planets
glow worms
jellyfish
atomic bombs
fireworks
paint used to stripe highways
electric stove cooking surfaces
neon lights
charcoal fires
wood fires
volcanoes
stars
bonfires
electrical storms
fireflies
cat's eyes at night
erupting volcanoes
hydrogen bombs
meteors
reflector tape
infrared lamps
ultraviolet lamps
gas stove burners
hot metals

Mimeograph for each child a copy of the list the class makes.

Discuss with the class the headings under which they think the things on the list can be organized. If the paired titles they suggest for classification incorporate the ideas in those that follow, use the children's titles without editing or rewording.

1.	Shine by their own light	Do not shine by their own light
2.	Produce light	Reflect light
3.	Light from living things	Light from nonliving things
4.	Light from organic materials	Light from inorganic materials
5.	Light accompanied by heat	Light not accompanied by heat

Divide the class into as many groups as they have suggested ways to classify the items on the list. Ask each child to cut from the list each item and place it under one of the two headings assigned to him. Have the children using the same headings compare their results. These children should settle any differences in the ways they have classified the items before they submit their group work to the class.

When the children in each group are agreed, mimeograph enough copies for every child in the class to have one copy of the work of each group. In a class discussion, ask the members of the group who made the classification to explain and provide the source of the information in defense of any questioned or challenged item.

Encourage the children to discuss, combine, evaluate, and improve the original wording of the paired classification titles.

The children should have developed the concept that some objects are seen by the light they produce and that others are seen by the light they reflect. Be sure they understand that some *cool* objects as well as *hot* objects produce, emit, or give off light. Also, they should realize that some living things as well as some nonliving things produce light.

Fireflies, glow worms, and many deep sea fish emit light. Some jellyfish and other plankton in the waters of the sea give off a phosphorescent glow. The light or glow they emit is a "cold light." Cat and other animal eyes do not produce light. Their eyes shine or glow because they reflect the light from automobile headlights or flashlights. Let the children discuss experiences they have had with these living things.

Some nonliving cool objects shine, glow, or emit light. Many objects shine by reflected light. Such objects are the reflectors attached to trucks, trees, highway guard rails, and fences. Have the children bring this type of prism reflector to school and demonstrate how the light of a flashlight reflects from the prism in the dark.

Other cool objects are painted, coated, or impregnated with fluorescent chemicals, which glow at night when light strikes them. Examples are the following: fluorescent adhesive tape, which is occasionally attached to the fenders of bicycles and the bumpers of automobiles and which is seen glowing when automobile headlights strike it; the white and yellow fluorescent paint used for marking some highways and guard rails; fluorescent gloves, hats, jackets, and overblouses worn at night by traffic police and firemen; fluorescent turnpike and interstate highway signs; and the speed limit signs of some states which read "55" in the headlights of traffic and which read "60" in daylight. Have the children obtain some of these materials for testing in class.

Phosphorescent chemicals are also used to paint, coat, or impregnate cool objects. After this phosphorescent chemical has been exposed to light, it will emit a glow. This glow is not visible unless it is dark. Such things as light switches, light switch plates, fish lures, and lamp bases glow because they have been treated with phosphorescent chemicals. Bring some things that are phosphorescent to school and compare the way they glow with the way fluorescent materials glow. See Chap. 6, Inquiry 6, for information about fluorescent and phosphorescent minerals.

Radioactive materials emit light directly and continuously. The dials and hands on some clocks and watches are painted with radioactive salts, which glow. Bring such a clock to school. Put it in a light, tight box in a dark closet for a week. Open the box in the dark at different times of day and on different days. Notice that it glows day after day without ever being exposed to light. See Chap. 11, Inquiry 3, for more information about radioactive materials.

7. What is the earth's most important source of light? Why is sunlight both a direct and indirect source of natural and artificial light?

Pupils probably know that the sun is the earth's most important source of light. The sun is either the direct or indirect source for both natural and artificial light. The stars, including the sun, and radioactive materials are primary, or direct, sources. The sun is the most important source because it provides the earth with the largest amount of natural and artificial light.

Have the children discuss and demonstrate how the light from the moon and the planets is really reflected sunlight and therefore comes indirectly from the sun.

Review the concept that living things need the energy in sunlight to grow, produce, and store food. Develop the understanding that fuels were once living things and that when fuels burn they release the stored energy obtained from the sun in the form of heat and *light*. Therefore the light from burning fuels comes indirectly from the sun.

Most of the light that is produced from electricity also comes indirectly from the sun. Electric power plants use either nuclear, steam, or water power to obtain the mechanical energy (energy of motion) that is needed to turn the generators that produce electricity. The heat released from burning fuels supplies the energy needed to change water into steam. Atomic power plants use the heat energy released by radioactive substances to change water into steam.

There would be no rain, rivers, streams, lakes, or oceans if the earth did not receive heat energy from the sun. Water could not exist in the liquid or gaseous state without the sun's heat.

The sun is also indirectly the source of the light emitted by some kinds of variable-temperature animals. Their light energy comes from the energy in the food they eat. Without the sun's energy they would have no food.

8. What is the difference between luminous and nonluminous objects? Why can we see nonluminous objects?

Have the pupils look up the meaning of luminous. (Emits light.) Help them to enlarge their vocabulary by developing an understanding of both luminous and nonluminous (does not emit light). Let them practice using the word luminous in some of its different forms in sentences: (1) illuminate, (2) illumination, (3) luminescent, (4) luminescence. Have the class review the two methods of classification they made in Inquiry 5 under the headings:

Shine by their own light	**Do not shine by their own light**
Produce light	**Reflect light**

Help them to understand that the headings can be combined and clarified if they are changed to read:

Luminous objects emit light
Nonluminous objects reflect light

Direct the beam from a focusing flashlight or from a filmstrip projector on a shiny piece of metal. Use chalk dust to make the beam visible. Ask several of the children to describe the path that the light takes from the source to the nonluminous metal and from the metal to their eyes. (The light, traveling to and reflecting from the metal, travels *in straight lines.*)

Review Inquiries 3 and 4. Ask the pupils to name some nonluminous objects they have seen in the sky at night. (Moon, planets.) Review the learning that these nonluminous objects are made visible by reflected light because light travels from the sun to the objects and then is reflected from these objects to their eyes. Have them also recall that people can see their reflection (image) in a mirror because the source of light is reflected twice. It reflects *from nonluminous people* to the mirror and *from the nonluminous mirror* to the eyes.

Help pupils to understand that they see all the countless nonluminous objects about them by the light that is reflected from these objects to their eyes.

9. How do different materials affect the transmission of light? What are good and poor transmitters of light called?

Make a collection containing clear and frosted glass, cellophane, white tissue paper, and heavy white cardboard. Try to shine light through each material when it is held tightly to the lens of a flashlight. Through which materials does the most light pass? (Clear or *transparent* materials.) Through which does no light pass? (Cardboard, an *opaque* material.) Through which does *some* light pass? (Semitransparent or *translucent* material.)

Discuss with the class what happens to the light that does not go through the opaque cardboard. (Part of the light is reflected from the cardboard and part is absorbed.)

Also, discuss what happens to that part of the light that does not pass through translucent materials. (Some of the portion that does not go through is reflected, and some is absorbed.)

Be sure that the students understand that even though transparent materials transmit a great deal of light they also reflect and absorb some light.

Give each child one piece of transparent food wrap, translucent paper, and opaque paper. Ask them to test each by holding it in front of their eyes. Which transmits the most light? (The clear transparent food wrap transmits so much light that objects on the other side of it are visible.) Which material transmits some light, reflects some, and absorbs some? (Translucent paper. Only *light, not objects,* is visible through translucent materials.) Which material transmits no light? (The opaque paper. It reflects some light and absorbs the remainder. Neither light nor objects are visible through opaque materials.)

Ask the pupils to name, collect (when possible), and classify other materials under the headings (1) transparent, (2) translucent, and (3) opaque. See Table 28.1 for materials children commonly suggest for classification.

Based on their observations, discussions, and classifications, help the children draw conclusions similar to these. When *no light is transmitted* through a material, it is described as opaque. When *most of the light that strikes a material is transmitted* through it, the material is described as *transparent*. Objects can be clearly seen through transparent materials. When *some light is transmitted* through a material, it is described as *translucent*. Objects cannot be clearly seen through translucent materials. Materials either reflect or absorb that portion of light which they do not transmit. Encourage the children to use the words *transparent, translucent,* and *opaque* when referring to materials that have these characteristics.

Table 28.1

REFLECTION OF LIGHT FROM TRANSPARENT, TRANSLUCENT, AND OPAQUE MATERIALS

Transparent	Translucent	Opaque
Eyeglasses	Tips of fingernails	Books
Watch crystals	Thin light-colored clothing	Soil
Windowpanes	Some buttons	Wood
Water	White or light-colored window shades	Metals
Air	Electric light bulbs	Rubber
Clear plastic package wrappings	Frosted glass	Floor tile
	Tissue paper	Ceramic tile
	Thin paper	Plaster
	Wax paper	Cement

10. Why do some surfaces look dull and others shiny? What is the light which is reflected from smooth shiny surfaces called? From rough dull surfaces?

Have the class make a collection of flat objects that have different textures, such as glossy and nonglossy paper, tarnished and shiny metal, varnished and unvarnished wood, nonglossy painted and unpainted wood. Ask the children to feel each of these objects and to classify them into groupings: 1) smooth materials, 2) rough materials. Have one of the pupils record their classifications on a large sheet of paper. Let the children shine a strong light on these materials and, by their reflected light, classify them as either 3) *dull, or* 4) *shiny*. Record these results on the same paper.

Discuss the results of the two different classifications the children have made. Find out whether they can combine the four groupings into two: 1) smooth and shiny, and 2) rough and dull. Encourage the *children to guess* why some of these objects look smooth and shiny, and others look rough and dull. These are some of the *guesses they may make:* 1) The surfaces of shiny objects have something on them that makes them shine. 2) Smooth surfaces reflect more light than rough surfaces. 3) The reflected light from smooth surfaces is more concentrated.

Give the class the opportunity to think of ways to find out whether their guesses are correct. The following experiments could be done as a check on the accuracy of their guesses. Examine the objects in the two groupings with a magnifying glass and observe the differences between their surfaces.

Cut a piece of painted wood into two pieces. Sandpaper the paint from the surface of one piece. Reexamine the two pieces. Which piece is shiny? Which is dull? The only other material suggested that has something added to its surface to make it look smooth and shiny is the piece of varnished wood. Some but not all surfaces have something on them to make them shine.

Cut a piece of unpainted wood into two pieces. Ask one child to rub the surface of one piece with fine-grained sandpaper. Call attention to the sawdust (pieces of the rough surface) that is being rubbed from the wood. Ask the children to examine the two pieces of wood with a magnifying glass and to rub their fingers over each. Does sandpapering cause the piece of wood to look and feel differently? Describe the difference between the two surfaces.

Darken the room. Use a small beam of light and chalk dust to help the class observe the light reflected from smooth surfaces and from dull ones. (The children will observe that smooth materials will reflect a beam of light that is almost as concentrated as the source. The reflected light from rough objects will be scattered or *diffused.*) Light reflected from smooth surfaces is called *regular reflection;* from rough surfaces, *irregular or diffused reflection.*

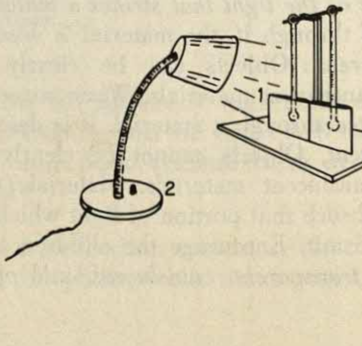
11. Which surfaces, smooth or rough, make better reflectors? Which surfaces absorb more light, smooth or rough ones? Why do rough dull surfaces absorb more light than smooth shiny ones? Why do rough dull surfaces make poorer image reflectors than smooth shiny ones?

Cut a piece of heavy transparent plastic into two strips, approximately 3 inches by 5 inches in size. Roughen the surface of one of the strips with steel wool to make it translucent. Lay the two strips on a table. Have the class observe which is a better reflector of light. (The smooth one.) Have them recall the difference between the light reflected from smooth surfaces and that reflected from rough surfaces. (Smooth surfaces reflect concentrated beams of light; rough surfaces reflect scattered or diffused beams.)

Let the children take turns looking through each piece of plastic at some object in the room. (The object will be clearly seen through the smooth transparent piece of plastic. The same object, if it can be seen at all, will look blurred through the translucent piece with the roughened surface.) Review with questions like these: (1) Through which piece of plastic does more light pass? (The clear, shiny, transparent piece.) (2) What happens to the light which does not pass through the rough translucent piece of plastic? (Some light may be *reflected* and some may be *absorbed.*)

The following experiment will help children understand that light energy that is absorbed produces heat and that rough dull surfaces absorb more light than smooth shiny ones. Fold each of the two pieces of plastic in half. Make these two folded pieces into separate envelopes by sealing the bottom and side with Scotch tape. Leave an opening in the top of each envelope large enough to insert a thermometer. Tape these two envelopes together to form a two-compartment envelope. Set up two thermometers, the two envelopes, and a lamp, as shown in Fig. 28.5. Insert the bulb end of a thermometer into each of the two compartments. Before the light is turned on, make certain that both thermometers indicate the *same room temperature* and that they are the *same distance from the lamp.* If these precautions are taken, the results of the

Fig. 28.5 Arrangement of equipment for discovering whether there is a difference in the amount of light absorbed by different materials. Two thermometers are placed equal distances from the light source. (1) Two-compartment envelope made of materials to be tested; (2) lamp with cone-shaped reflector.



experiment will show that more light is *absorbed* by the *translucent compartment* with the rough dull surface than by the transparent one with the smooth shiny surface. The light that is absorbed is changed into heat. Heat energy causes the liquid in a thermometer to rise. The thermometer in the rough translucent envelope will read higher than the thermometer that is enclosed in the compartment made of transparent smooth shiny material. Repeat this experiment several times so that the class will be convinced that the result is not accidental. Also, reverse the positions of the compartments and check the results again. This recheck will eliminate any ideas pupils may have that either the right or left compartment receives more light energy than the other.

Repeat the previous experiment by making envelopes from at least two other kinds of materials. The dull and shiny sides of opaque aluminum foil could be used for one set of testing materials. Either shiny dark-red or dark-blue opaque construction paper would be a good second choice of materials. Cut the shiny paper in half. Roughen the surface of one piece with a knife. (The results of tests with the foil and colored paper will provide further evidence that dull, rough surfaces of the *same material* absorb more light and heat energy than smooth, shiny ones.)

Find out whether the class can think of a reason that explains why rough surfaces absorb more light and heat energy than smooth ones. (Rough surfaces have more area to absorb this energy than smooth ones do.) Wrinkle a piece of aluminum foil. Partially straighten and flatten the foil, being careful not to remove all the creases. Lay this wrinkled foil on an unwrinkled piece. Cut through the two pieces at the same time to get pieces that are identical in size and shape. Now rub and smooth as many creases as possible from the wrinkled foil. Ask the children to compare the difference between the two pieces. (The piece that was wrinkled has a larger surface area than the other. When it was wrinkled and the same shape as the other, it also had more surface area.) Discuss the reason why closely woven cloth with rough texture is warmer than the same kind of cloth with smooth texture. Obtain samples of cloth that have these two different textures and examine them with a magnifying glass. Call attention to the larger surface area of the samples that have rough textures.

Also, find out whether the class can explain why smooth shiny surfaces make better image reflectors than rough dull surfaces. Let children compare their images in both the dull and shiny sides of aluminum foil. (Light reflected from rough surfaces is so scattered and diffused it causes a blurred image.)

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. There must be something to see. We must have enough light to see it. We must use our eyes to see.

2. The light from a flashlight and the light from the sun traveled in a straight line through the hose. We could see small objects through the hose when it was in a straight line.

3. Mirrors reflect light. Many other smooth, shiny surfaces are also good reflectors. The best reflectors have the smoothest and shiniest surfaces.

4. We can see our own image or another person's image in a reflector because the light is reflected twice—once from the person to the mirror, and again from the mirror to someone's eyes. Reflectors have many uses.

5. We see most objects because they reflect light to our eyes.

6. Some kinds of things *produce or emit light*. Other things shine because they *reflect light*. Light is produced by some kinds of *nonliving* material and also by some kinds of *living* things. Most nonliving things that produce light do this when they are very hot; however, some do not need to be hot in order to glow. Some living organisms also glow or emit "cold light."

7. The sun is either directly or indirectly the major source of light on earth. Light from the sun and other stars is a direct source of natural light. Because light from the moon and planets is reflected sunlight, it is an indirect source of sunlight. Electricity and fuels also are indirect sources of sunlight.

8. Luminous objects emit light. Nonluminous objects do not emit light. There must be a source of light to make nonluminous objects visible. Nonluminous objects are made visible by reflected light.

9. Materials differ greatly in their ability to transmit light. Those materials which transmit the most light are called *transparent;* those that transmit some light, *translucent;* those that transmit no light, *opaque.* Materials reflect and absorb that portion of light which they do not transmit.

10. Materials with smooth surfaces usually look shiny. Materials with rough surfaces usually look dull. The light reflected from smooth surfaces is *more concentrated* than the light reflected from rough surfaces. Rough surfaces scatter or *diffuse* reflected light. The reflected light from smooth surfaces is called *regular reflection.* The reflected light from materials that have rough surfaces is called irregular or *diffused reflection.*

11. Smooth shiny surfaces make better reflectors than rough dull ones. An object will absorb more light and heat energy if its surface is rough and dull than it will if its surface is smooth and shiny. An object that has a rough surface has more area to absorb light and heat energy than it does when it is smooth and shiny. Rough dull surfaces makes poorer image reflectors than do smooth shiny surfaces. Rough surfaces scatter and diffuse the light reflected from them in a degree proportional to their roughness.

Chapter Twenty-Nine

Light and Color

INQUIRIES

1. How do black, white, and colored materials look in dim light? Does black absorb or reflect more light energy? Does white absorb or reflect more light energy? Do light or dark shades of the same color absorb or reflect more light energy?

2. How much of the visible spectrum do nonluminous, white and black, opaque objects reflect? When do nonluminous opaque objects look white or black? Why are black and white not colors?

3. What parts of the visible spectrum do colored opaque objects reflect?

4. What parts of the visible spectrum do colored transparent materials transmit?

5. What are some common uses of light filters?

6. What happens when the colors of the spectrum are recombined? What is the process called when two or more colors in white light (components of the spectrum) are mixed? What colors are produced by adding different combinations of red, green, and blue light? What happens when different amounts of red, green, and blue light are added?

7. How do pigments determine the color of nonluminous materials? What happens when pigments are mixed? What three pigments can be mixed to produce the visual sensation of white?

1. How do black, white, and colored materials look in dim light? Does black absorb or reflect more light energy? Does white absorb or reflect more light energy? Do light or dark shades of the same color absorb or reflect more light energy?

Review the experiences with the colors of the visible spectrum in Chap. 27, Inquiry 1.

Have the children make a collection of colored materials, which match as nearly as possible these five spectral colors: red, yellow, green, blue, and violet. (Some books list orange as a sixth spectral color.) Also, include black and white samples of some materials.

Discuss with the class whether they have observed what happens to colors and to black and white in dim light. Ask them to plan experiences either to help them find out what happens or to test their ideas. They may suggest experiences similar to those that are suggested here.

Ask the pupils to take the black, white, and colored materials they have collected into a dark closet. A dim light can be obtained by opening the door only enough to admit a small amount of light. (White and light-colored materials will appear to be gray or grayish black. Black and dark-colored materials will appear to be black.)

Cut four-inch squares from white and black paper. Paste each in the middle of a larger sheet of black paper. Fasten these two large sheets of black paper on the wall of the dark closet. Ask the children to find out which small square (white or black) can be seen in the smaller amount of light. (The white one can be seen in dim light. It will appear gray.)

Ask the children to make the following observations at home. Tell them when they go home in the afternoon to select one colored object outdoors and observe its color carefully. This object could be a house, flower, lawn, clothes on the clothesline, and so on. Ask them to look at it a second time in twilight, which occurs after sunset, and a third time after dark. In class the next day, ask them to report on how the color of the object they selected changed as the light grew dimmer.

Have each child make a pinhole viewer by punching a pinhole in a piece of black paper. Arrange colored materials on a bulletin board for viewing. Ask them to look carefully at one of the colors with one eye and then, with the same eye, to look at it through the pinhole. (The colors change in intensity in the small amount of reflected light that can come through the pinhole.) Use viewer to look at the scenery through the classroom windows. Observe colors and scenery with the eyes open wide and then nearly closed. Do the same changes occur?

Collect at least three shades of red, yellow, green, blue, and violet paper. Paste the lightest shade of each color in a row across a large piece of paper. Match and paste the more intense shades in a row below and, finally, the most intense in the bottom row. Fasten the paper on the closet wall. View in dim light. Which shades can be seen with the least amount of light? (The lightest shades which are in the top row.)

Ask the class why they think white and the lightest shades of color can be seen in the dim light. They should remember that all nonluminous materials are seen by light reflected from objects to their eyes and that they see nothing when no light is reflected. For these reasons, they may assume that white and light-colored materials reflect more light than black and dark-colored things, and that black and dark-colored materials absorb more light. Ask them to help you plan ways to test this assumption. Encourage the use of a wide variety of resources.

The following experiment should be helpful. Obtain four identical screw top jars. Put equal amounts of ice water and an aquarium thermometer in each jar. Screw on the covers. Make certain that the four thermometers read the same. Completely wrap and cover two of the jars with heavy black paper and two with white. Set all jars in a sunny window. Unwrap and record the temperatures in the jars at 30-minute intervals for a period of several hours. Which jars gained more heat? (The two with black paper.) Which jars absorbed more of the sun's energy? (The two with black paper.) Remind the class that both the white and black paper were heavy and opaque enough to prevent transmission of light into the jars, and that the sunlight, therefore, can only be absorbed or reflected from the paper. If the black paper *absorbed* light energy, what did the white paper do? (It *reflected* light energy.) Encourage the children to guess why four jars were used for this experiment instead of two. (There is less chance that the results will be accidental. Repetition also will reduce this chance.) The experiment should be repeated several times to confirm the first results. If the results are uniform, they can make such tentative conclusions as these:

1. **Black paper seems to *absorb* more and *reflect less* of the sun's energy.**
2. **White paper seems to *reflect* more and *absorb less* of the sun's energy.**
3. **Probably all black materials absorb more and reflect less of the sun's energy. Probably white materials reflect more and absorb less of the sun's energy. (This can be checked by using cloth wrappings and by painting the jars with black and white water paint.)**

Select the following sheets of construction paper: black, white, dark red, light red, dark blue, and light blue. Make certain that the sheets are the same texture and weight. Have several pupils make two-compartment envelopes (like those described in Chap. 28, Inquiry 11). Pair the sheets this way: (1) black and white, (2) dark red and light red, (3) dark blue and light blue. Arrange thermometers, compartments, and lamp as shown in Fig. 28.5. Ask the children to test each pair to find out whether black absorbs more energy than white, and whether the darker or lighter shades of a color absorb more energy. Tell the class to repeat the test for each set several times and to record the results. (The results should show that black absorbs more and reflects less light energy than white, and that darker shades of colors absorb more and reflect less light than lighter shades of the same color.)

Cut two pieces of white cloth into six-inch squares. Soak one piece in thick white water paint and the other piece in thick black water paint. Hang them up and let them drip dry. In this way, each piece should have the same amount of paint. When the two pieces are dry, wrap one piece around the bulb end of one thermometer and the other piece around the bulb of a second thermometer. Hang the thermometers in a sunny window for at least an hour. Before reading the thermometers, have the children predict the results. (The temperature of the thermometer that has the black cloth wrapped around it should be higher than the one with the white cloth.)

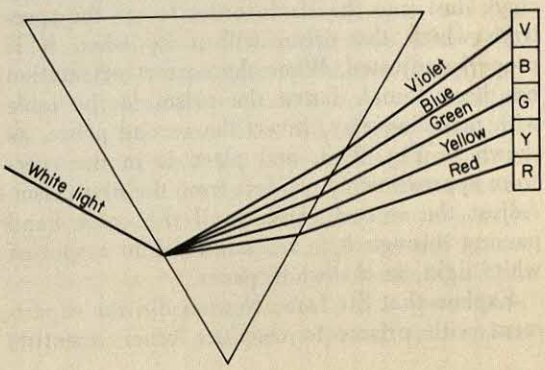
Find out if the students can apply what they have learned to these questions:

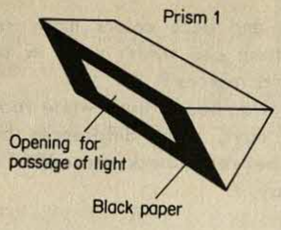
1. **Why are white and the lighter shades of colors more comfortable to wear in tropical zones?**
2. **Why are white and light colors more comfortable to wear in the summer in temperate and frigid regions?**
3. **Why are black and dark colors more comfortable for autumn and winter wear in temperate and frigid regions?**
4. **Why do most Florida houses have white roofs?**
5. **On hot, sunny days, what differences have you observed between black macadam and concrete highways?**

2. How much of the visible spectrum do nonluminous, white and black, opaque objects reflect? When do nonluminous, opaque objects look white or black? Why are black and white not colors?

Review the experiences and learnings in Chap. 27, Inquiry 1, and in Chap. 28, Inquiry 8. Help the children to understand that both sunlight and white artificial light are composed of the visible light colors seen in the spectrum. Set up a 60-degree prism (a wedge-shaped piece of glass with sides of equal width) as shown in Fig. 29.1. Turn the prism in a beam of white, artificial light until the angle is found at which the band of color called the spectrum is visible on a nearby wall. When this angle is found, mount the prism in some modeling clay and then tape a piece of *white paper* on the wall where the "rainbow" colors appear. Record the position of each of the "rainbow" colors in the spectrum by printing the first letter of the color's name as shown in Fig. 29.1. Be sure that the pupils realize that the

Fig. 29.1 White light is a mixture of colors. The prism separates this mixture into a band of colors called the *visible spectrum.* The spectral colors in white light are refracted and dispersed (separated) as they pass through the prism into the air. Notice that the color in white light which travels the greatest distance through the glass is refracted the most.





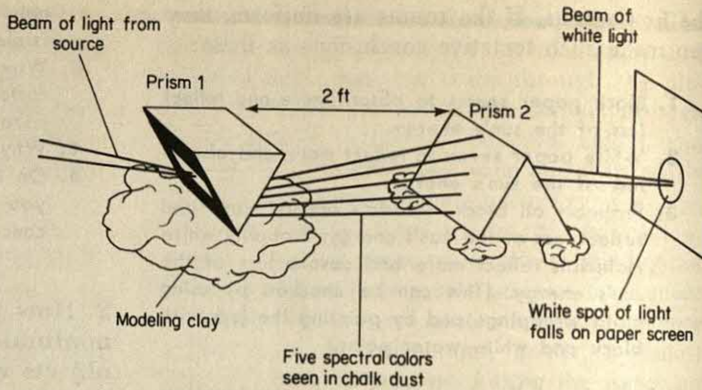

Beam of light from source
Beam of white light
Prism 1
2 ft
Prism 2
Modeling clay
White spot of light falls on paper screen
Five spectral colors seen in chalk dust

Fig. 29.2 (*left*) Cover one side of prism 1 with black paper in which an opening about ¼-inch wide has been cut.

Fig. 29.3 (*right*) The spectral colors can be recombined to form white light.

white paper is reflecting each and every one of these colors to their eyes.

Cover the white paper with a *black paper*. Why are the spectrum colors so dim? (Black paper absorbs more of the spectral colors than white paper.)

Discuss why white and black are not colors. (White is not *one* color; it is *the reflection of a combination of certain colors of the visible spectrum*. Black is not a color; it is *the absence of color*.)

Some of the pupils may wish to try a much more difficult experiment with white light. They will need two prisms, an artificial source of white light, some modeling clay, a piece of white paper, and a table at least three feet long on which to set up the experiment. Cover one side of one prism with black paper in which a narrow opening ¼-inch wide has been cut. (See Figs. 29.2 and 29.3.) Adjust the first prism until it separates the white light into the spectral colors. Clap chalk dust into the air in order to see the spectrum which the prism will make when it is properly adjusted. When the correct orientation has been found, fasten the prism to the table with modeling clay. Invert the second prism, as shown in Fig. 29.3, and place it in the spectrum approximately two feet from the first prism. Adjust the second prism until the color band passing through it is recombined into a spot of white light on the white paper.

Explain that Sir Isaac Newton did the experiment with prisms to convince other scientists that white light is a combination of colors. Ask for volunteers to read about Sir Isaac Newton's experiments with light and report to the class what they learn.

3. What parts of the visible spectrum do colored opaque objects reflect?

Obtain heavy red, yellow, green, blue, and violet paper to match as nearly as possible the five colors in the visible spectrum. Repeat the experience with a prism as shown in Fig. 29.1. Allow the spectrum to fall on each of the colored papers. Observe and record the spectrum color which is predominantly reflected from each colored paper. (Red paper reflects more red light than any other color of light. Green more green light, blue more blue, and so on.) Repeat and observe which colors are *not* predominantly reflected by the various colored papers. What has happened to these colors? (They are largely absorbed.) If your violet paper is really purple, it will reflect both red and blue light.

4. What parts of the visible spectrum do colored transparent materials transmit?

Obtain transparent cellophane to match as nearly as possible the red, yellow, green, blue, and violet colors in the spectrum. Also, get a piece of clear, colorless cellophane. Ask the children to repeat the experiment shown in Fig. 29.1, using sunlight for the source of white light. When the adjusted prism produces the spectrum on the white paper, have the children test each piece of cellophane to find out which of the five colors it transmits. Each color of cellophane can be tested by looking through it at the visible spectrum on the white paper. Observe and record the colors of the spectrum which pass through the cellophane to the eyes. Ask the pupils to underline the recorded name of the predominant color that passes through each piece of cellophane. (The five colors in the spectrum will pass through the colorless cellophane. They will look less intense because the cellophane *absorbs some of each light color*. The red light will pass through the red cellophane. The other four colors either will not be transmitted or will be very weakly transmitted by the red cellophane, because the red cellophane will *block out, absorb,* or *subtract* most of the other colors in light. More blue light passes through blue cellophane; more green light, through green; more yellow light, through yellow; and so on.) Be sure the children understand that transparent materials, such as colored cellophane and glass, are called *light filters* because they transmit more of a certain color or group of colors in the spectrum and block the passage of others by *absorbing* or *subtracting* them. The pupils can vary the preceding experience by holding each piece of cellophane (1) so that a single layer of it completely covers the side of the prism through which the sunlight is entering; and (2) so that a single layer of it completely covers the side of the prism through which the spectrum is leaving.

5. What are some common uses of light filters?

Discuss some of the uses of colored filters. (Sun glasses, colored filters for theater spotlights, colored filters for cameras, colored glass Christmas tree light bulbs, colored glass for traffic lights, colored glass for automobile lights, revolving colored filters for spotlighting metallic Christmas trees, and so on.) Ask the children to bring and demonstrate some of these filters. Invite a photographer to show the class some of the filters he uses and the pictures he has made with them. Ask him to explain why he uses filters and why they produce the effects he wants.

Make plans with your class to visit a theater or school auditorium where the stage lighting includes the use of colored spotlights. Ask the children to try to wear something red, yellow, green, blue, and so on, when they go on the trip. During the visit to the darkened auditorium, have the children observe the effect of the different colored spotlights on their colored clothing. Ask them to explain why their blue clothing looks black in a red spotlight. (The blue clothing reflects blue light and absorbs other light colors. The red light cannot be reflected to the eyes of the audience from blue clothing because the red light has been absorbed or subtracted by the blue clothing.) Ask them why their red clothing also looks black in a blue spotlight. Try each of the different colored spotlights on each color of clothing and record the results. After the pupils have returned to the classroom, have them try to explain each of the results. The same results can be demonstrated less dramatically in a dark closet with colored papers illuminated by filtering the light from a flashlight beam with different colors of cellophane.

6. What happens when the colors of the spectrum are recombined? What is the process called when two or more colors in white light (components of the spectrum) are mixed? What colors are produced by adding different combinations of red, green, and blue light? What happens when different amounts of red, green, and blue light are added?

Review the experiment shown in Fig. 29.3, Inquiry 2. (When all the spectrum colors are recombined, white light results.)

The following tests can be done with either three identical filmstrip projectors or three identical flashlights. Make certain that the flashlight dry cells are new. Use red, green, and blue cellophane to cover the lenses of the three sources of light. Shine the red light on a white screen. Red light will be reflected from the screen to your eyes. Shine the green light on the screen. See the green reflected light. Shine the blue light and see the blue light reflected to your eyes. Now make a red and green spot of light appear

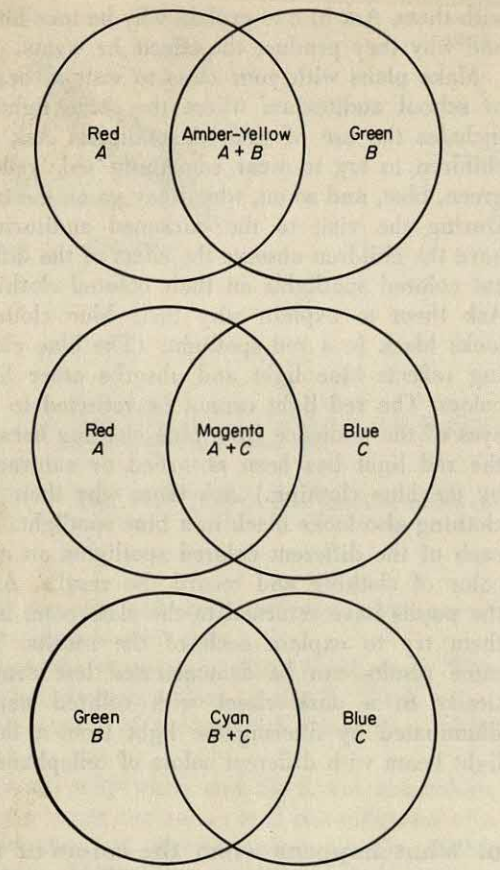
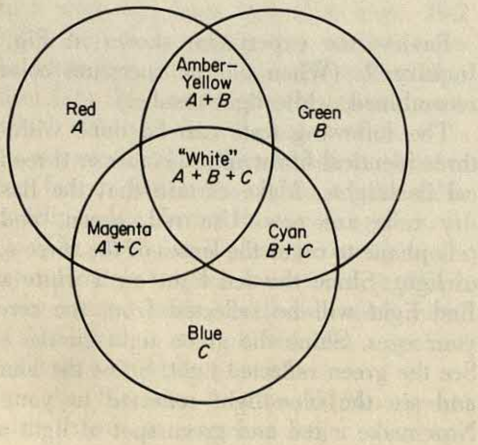


Fig. 29.4 Additive mixing of colored light.

Fig. 29.5 Mixing of colored lights (additive process). Colored light *components: A*, red light; *B*, green light; *C*, blue light. Colored light *additives:* $A + B$, amber yellow; $A + C$, magenta; $B + C$, cyan; $A + B + C$, "white."



side by side on the screen. Overlap the two. What do you see? (Yellow that is called *amber yellow.*) Help the children to understand that when green and red light are combined in this way, the combination is called the *additive process* of mixing two or more *colors of light.* (See Fig. 29.4.) Add red and blue light in the same way. What color results? (A reddish purple called *magenta.*) Add green and blue light. What color results? (A blue green called *cyan.*) Add red, green, and blue light. What is the result? (A grayish white.) Why is this not a true white light? [There are two reasons: (1) it is the addition of only red, green, and blue light. The yellow and violet spectral light colors which are also in white light are missing. (2) The three colored cellophanes only approximate those colors of the spectrum.] See Chap. 34, Inquiry 2, on one theory of how eyes receive red, green, and blue-colored light and from these colors produce the sensation of white light.

Try to overlap the red, blue, and green lights to produce the colored light additives of amber-yellow, magenta, cyan, and white (see Fig. 29.5).

Try to show, by combining varying amounts of red, green and blue light, that it is possible to produce a wide range of color sensations. Encourage other pupils to find out and report to the class the three light components used in color television. The additive process used in color television produces the sensation of a wide color range by combining three colors of light (red, green, and blue). Ask those pupils who have color television at home to find out how the amount of red, green, and blue on the picture tube can be controlled by the viewer. (By the color knob.)

7. How do pigments determine the colors of nonluminous materials? What happens when pigments are mixed? What three pigments can be mixed to produce the visual sensation of white?

Help the children make a list of the learnings developed earlier in this chapter which apply to this inquiry, similar to the one that follows:

1. **Only part of the light which strikes a nonluminous colored object reaches the eyes; the rest is absorbed by the material.**

2. The color of a nonluminous material depends on the predominant colors of light received by the eyes.
3. Some colored nonluminous materials (opaque ones) *reflect* to the eyes light of a predominant color or colors and *absorb* the light of other colors. Some other materials (transparent ones) *transmit* light of a predominant color or colors and *absorb* the light of other colors.
4. The colors of light which are absorbed are *subtracted* from the light source.
5. Three colors of light—red light (*A*), green light (*B*), and blue light (*C*)—can stimulate the eyes to produce the sensation of "white" ($A + B + C$) light (see Fig. 29.5).
6. If the *amounts* of red, green, and blue light that the eyes receive are controlled, the eyes are stimulated to produce the sensation of a *wide range of colors.*

Show the pupils colored papers, cellophane, plastic, glass, crayons, paint, cloth, pottery, leaves, flowers, colored animals, and so on. Explore their ideas about what they think colored nonluminous materials *contain*: (1) to reflect some of the colors in a light source, and (2) to subtract others by absorption. (Colored nonluminous materials contain *colored pigments.*) Assist the children in locating recently published information on how pigments control colors. Information similar to the following can be found in recent editions of encyclopedias, elementary physics books, and trade books on light and color.

Paints, dyes, and inks contain many tiny colored particles called *pigments.* Each of these particles acts like a color filter, which transmits light of its predominant color and subtracts, or removes by absorption, other colors of light. *Even an opaque material is somewhat transparent. When light strikes the surface of a white or colored opaque object, certain colors of light pass through the pigment-like filters in the surface of the object and are reflected back through the pigment filters a second time to the eyes of observer.* For example, the pigment-like filters in white paint transmit light that contains *all the light colors* needed to produce the sensation of white. When an object looks colored, *only some of the colors* in light pass through the pigment-like filters and return to the eyes of the observer. The rest of the colors in white light are absorbed by the pigments.

Obtain packages of red, yellow, and blue fabric tints. These tints or dyes are pigments. Before the pupils start to work with these tints, discuss the precautions they should take. (The dyes will stain such things as clothing, furniture, and some metals. Care should be taken to avoid spilling any dye solutions. For protection, the tabletop should be covered with newspapers. The pupils who work with dyes should wear either aprons or smocks to protect their clothing, and they should wash their hands after they have finished their work. Always store and work with dye solutions in glass containers. Handle the dry pigment grains with spoons because the moisture of the fingers can cause these pigments to stain the hands.)

With magnifying glasses, examine a few of the dry grains of tint in each of the three packages. Note the shapes of the grains. (Without a magnifying glass, the grains of the dry tint will appear to be round. With the magnifying glass, multiple sided grains can be seen.)

Prepare solutions of each of these pigments. Use either hot or cold water as directed on the package. Place one level tablespoon of each tint in a separate glass measuring cup or in a pyrex beaker. Add one cupful of water to each, and stir until the grains have dissolved. Strain each of the solutions through a piece of nylon stocking to remove impurities. Store in glass containers with tightly fitted lids.

Pour part of each pigment solution in separate large-mouthed jars. Suspend a piece of unglazed string in each jar and let the jars stand until the water evaporates. The pigments that were dissolved in the water will form crystals on the strings. The crystals will be large enough to be visible with a magnifying glass.

Use some of the dye solutions in the storage jars to help children analyze what colors of spectral light are transmitted and absorbed by each tint. Put enough water in a *glass* baking dish to cover the bottom to a depth of about two inches. Slowly pour one of the dye tints into the water and stir with a glass rod until the dye is thoroughly mixed with the water. (It is not necessary to heat either cold or hot water tints *during this dyeing process.*) Float a piece of thin white tissue paper on the solution. (The size of the tissue depends upon the size of the container. Several two- by two-inch squares are ample for the experiments that follow.) Use a glass stirring rod to push the paper squares gently to the bottom of the dye bath. Leave the tissue paper in the solution for approximately two minutes. Remind the class that tissue paper tears very easily when it is wet and that these directions should be followed when the paper is removed from the bath. Lift one corner of the paper with a stainless steel knife or a wooden tongue depressor. Insert a piece of wax paper underneath the tissue paper and "tease" some of the solution over the tissue paper. Gently "swish" the wax paper, on which the tissue paper is floating, up and down and back and forth in the solution until the tissue paper clings smoothly to the wax paper. The paper is now ready to be removed from the dye bath and to be placed on newspapers to dry. *Do not attempt to remove* the tissue paper from the wax paper until it is dry. Observe the transparency of the tissue paper when it is wet. The children will be able to read the print on the newspaper through the wax paper and the wet tissue.

Use the same procedures to dye pieces of tissue paper in dye solutions of the two other tints. When the pieces of tissue paper are dry, cut a 40 mm (millimeter) or approximately 1½ inch square from each of the three different pieces of tinted paper. Place these dyed squares on white paper. What color sensation does the eye record from the *reflected* light? (Red, yellow and blue.)

Place these squares in 35-mm ready-mounts. The mounts can be obtained from a camera shop. Borrow a 35-mm slide projector. Project each slide on the screen. What color sensations does the eye record from the light *transmitted through* the slides to the screen and then *reflected* to the eyes? (Red, yellow, and blue.)

What colors of light are transmitted and absorbed by the colored tissue paper filters?

Remove the tinted slide from the projector. Hold a glass prism in front of the lens of the lighted slide projector, and adjust the prism until it is at the proper angle and distance from the lens to form on the ceiling a complete spectrum from the white light emitted by the projector lamp. Mount the prism in this position. (The prism can be attached to a piece of cardboard with modelling clay and supported at the proper height with several books.)

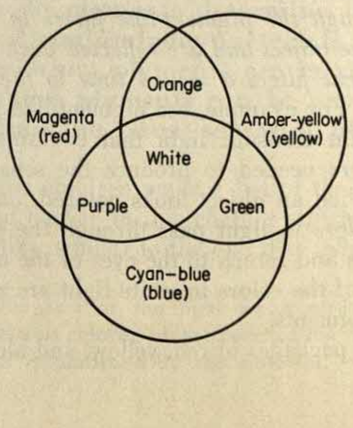
Reinsert one tinted slide in the slide holder in the projector. Observe the change in the spectrum that now appears on the ceiling. Make certain the pupils understand that this spectrum contains the colors of the light that are *transmitted through* the tinted slide. Also make certain they understand that the colors missing from the spectrum are *absorbed* by the slide. Insert the second tinted slide and then the third tinted slide, and observe the different spectrum formed by each one.

Ask the class to name the predominant colors that were visible in the spectrum formed from the light transmitted through each of the dyed filters. (There were two dominant colors, *red and blue,* in the spectrum of the red dyed filter. The spectrum of the yellow dyed filter had *red and green* as dominant colors. The two dominant colors in the spectrum formed by the blue dyed filter were *green and blue.*) How would a scientist rename the red, yellow, and blue filters in these slides? (Magenta red, amber yellow and cyan blue. See Fig. 29.5.)

Try mixing equal amounts of the magenta red and amber yellow dye solutions. What is the result? (A yellow red, commonly called *orange,* is produced.) Combine the solutions of amber yellow and cyan blue. Color? (*Green.*) Combine magenta red and cyan blue. Color? (*Purple.*) How many colors of dye do you now have? (Six: red, yellow, blue, orange, green and purple. See Fig. 29.6.)

Encourage some of the students to dye tissue paper in the orange, green, and purple solutions and to use the slide projector and prism to examine the predominant colors of light the dyed tissue papers transmit.

Fig. 29.6 Mixing of colored pigments.



Experiment with the pigments—red, yellow, and blue—in artist's water colors. Flow a water-wash of "yellow" on water color paper. While the "yellow" is still wet, flow a wash of "red" over the paper so that a part of it covers some of the "yellow." What is the result? (A yellow red, commonly called orange.) Use a "blue" wash over "yellow." What color is approximated? (Green.) Use a "red" and "blue" wash in the same way. Color? (Purple—approximating the spectral color, violet.)

Repeat the same combinations with red, yellow, and blue crayons. Why are the results similar? (Crayons contain pigments also.)

Encourage the pupils to plan other ways to mix the red, yellow, and blue pigments to produce the color sensations of orange, green, and purple. They may wish to intermingle the small dry grains of these pigments on paper and observe the results from a distance.

Ask the children to bring colored comic strips to school. Have them examine the colors in them with a magnifying glass. What colors of dots can be seen? (Red, yellow, and blue.) Examine closely an orange, green, and purple area of the comic strip. What colored dots produce the sensations of orange? (Red and yellow.) Of green? (Yellow and blue.) Of purple? (Red and blue.)

Ask some of the pupils to read and to report on the four-screen process used for printing colored pictures in newspapers and magazines. (They use three screens. One screen for the red ink, one for the yellow ink, and one for the blue ink. These three colors of ink can produce many color sensations. To obtain a depth of color, a fourth screen for black ink is used.)

Have the class look closely at some colored filmstrips. What dyes have been used? (Red, yellow, and blue.)

Make a color wheel. Cut a four-inch disc from white cardboard. Draw three pie-shaped sections on the disc and color them with red, yellow, and blue crayons. Crayons contain pigment colors. Red, yellow, and blue pigments are really the colors magenta red, amber yellow and cyan blue. Insert a pencil through the center of the disc. Roll the pencil back and forth *slowly* between the palms of both hands. Ask the pupils what they think will happen if the color wheel is rotated very rapidly. (The individual colors will disappear.) What may result? (A grayish white.) Why? (A review of the information contained in Fig. 29.6 will help the pupils understand why the three pigments, magenta red, amber yellow, and cyan blue, can produce the sensation of white. The magenta red section *reflects red and blue light* to the eye; the amber yellow section *reflects red and green light* to the eye; and the cyan blue section *reflects blue and green light.* The other colors of light have been *absorbed* by the three crayons. Together the three sections have reflected red, blue, and green light. *Red, green, and blue light* combine to stimulate the eye to sense white. See No. 5 in the list of review learnings at the beginning of this inquiry. Vary the proportions of red, yellow and blue crayon on the discs to see if a whiter white can be seen.)

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. White and less intense shades of color look gray or grayish black in dim light. Black and dark colors look black in dim light. Black materials absorb more and reflect less sunlight. White materials reflect more and absorb less sunlight. Light shades of a color reflect more and absorb less sunlight than dark shades of the same color. When the sun's energy is absorbed, it often changes to heat energy.

2. Nonluminous white, opaque objects reflect most of each spectral color in white light. Nonluminous black, opaque objects absorb most of each spectral color in white light. What we call white is a combination of reflected colors. Black is the absence of reflected colors. Light that contains all of the spectral colors is called *white light.*

3. The color of an opaque object is determined by the predominant color it reflects.

4. Colored transparent materials are called light filters because they selectively block out, filter, absorb, or *subtract* parts of the visible spectrum. The color of the filter determines which part of the visible spectrum will be transmitted and which part will be absorbed.

5. Light filters have many practical uses.

6. White light results when the component colors of the spectrum are combined. The mixing process of overlapping light components is called the *additive process* of mixing colors. By the additive process, controlled amounts of red, green, and blue light can produce the illusion of white and the sensation of seeing a wide range of colors. The light components used in colored television are red, green, and blue.

7. Variations in the amount of red, green, and blue light received by the eye produce the visual sensations of white and a wide range of colors. Colored filters *transmit* some of the colors of light and *absorb* others. In this way the pigments used in paints, dyes, crayons, and inks are like colored filters. The pigment color magenta red transmits red and blue light to the eye; amber yellow transmits red and green light; and cyan blue transmits blue and green light. From these three pigments, the eye receives red, blue, and green light. The eye combines these three colors of light to cause the visual sensation of white and of a wide variety of colors depending upon the amounts of each color of light received by the eye. Red, yellow, and blue pigments are used in processing colored film and in printing colored pictures and comic strips. Sometimes artists who work in color use only the red, yellow, and blue pigment colors to achieve the sensation of all colors.

Chapter Thirty

Color, Everywhere Color

INQUIRIES

1. What kinds of things contain the pigments used to make dyes, inks, and paints? How are pigments extracted? What is one difference between a dye and a paint?

2. Where are pigments located in green plants? What causes the fruits and leaves of plants to change colors?

3. Why are pigments important to plants?

4. Why are pigments important to animals?

5. What are some of the explanations for the color sensations produced by things that lack pigments?

1. What kinds of things contain the pigments used to make dyes, inks, and paints? How are pigments extracted? What is one difference between a dye and a paint?

Have the children list natural things in their environment that are colored. (See Tables 30.1, 30.2, 30.3, 30.4.) Try to confine the early experiments and discussion to the problem of color sensations *produced by the pigments* in living and nonliving things.

Pupil activities

1. Examine a collection of the things on the list that contain pigments. Some members of the

Table 30.1

SOME COLORED LIVING THINGS THAT DO AND DO NOT CONTAIN NATURAL PIGMENTS

Color Caused by Pigment	Color Not Caused by Pigment
1. *Nongreen plants*	1. *Nongreen plants*
The spores of many different kinds of fungi	(No examples)
2. *Green plants*	2. *Green plants*
Most roots, stems, bark, leaves, flowers, fruits, and seeds	(No examples)
3. *Animals*	3. *Animals*
Fur, hair	(No examples)
Skin	
Many feathers	Blue feathers: bluebird, bluejay Metallic blue feathers: grackle Iridescent feathers: peacock, hummingbird
Brown eyes	Blue eyes
Chitin: the cover of some animals such as insects and shrimp	Metallic blue: bottle fly, Japanese beetle Iridescent: wings and bodies of some insects
Many shells	Pearly lustered shells: oyster Iridescent shells: abalone
Red blood: hemoglobin	(No examples)
Blue blood: crayfish, lobster	(No examples)

class may have personal collections of rocks and minerals, shells, insects, and so on, which the children may bring to school. Supplement their collections with those that the school may have.

2. Collect and extract a variety of colored pigments from the different parts of green plants, such as flowers, fruits, seeds, leaves, bark, and roots. Either pyrex cups or beakers make good containers for pigment extractions. Cut, crush, grind, or tear the selected plant samples into small pieces and place in separate cups. Add enough water to cover the pieces in each of the cups. If the pigments do not show in the water, heat may be required to extract them. Place the

Table 30.2

SOME COLORED NONLIVING THINGS THAT DO AND DO NOT CONTAIN NATURAL PIGMENTS

Color Caused by Pigment	Color Not Caused by Pigment
1. *Minerals*	1. *Minerals*
Amethyst; violet*	*Brilliance*, *sparkle*, *luster*, and *iridescence* of minerals; diamonds, pearls, mica, coal
Citrene quartz; yellow*	
Emerald; green*	
Gold; purple	
Iron oxides; rust colors—red and yellow	
Mercuric sulfide—scarlet red or vermillion	
Ruby; red*	
Sapphire; blue*	
Silver oxide; yellow	
Sulfur; yellow	
Sulfur dioxide; tarnish on silverware	
2. *The Atmosphere*	2. *The Atmosphere*
Solid foreign particles; dust, pollen, spores (caused by the suspension of these colored particles in the colorless gases of the atmosphere.)	Blue sky Rainbow Moonbow; sometimes seen on winter nights Sunrise Sunset (caused by the different densities in the transparent atmosphere and the transparent water and ice in it and by the angle at which light is transmitted and reflected by them.)

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* Colors caused by small amounts of mineral impurities (pigments) that are *mixed*, not chemically combined, in these gem stones.

Table 30.3

PIGMENTS CAUSE SOME ROCKS AND MINERALS TO BE COLORED

Color	Rock or Mineral	Pigment Chemical
Red yellow, yellow red	Rust, soft earthy masses of iron oxides	Iron oxide { Red ochre-hematite Yellow ochre-limonite
Blue green	(Bottoms of copper dishes)	Copper oxide
Colorless	Clear quartz or rock quartz	No chemical producing pigment
Violet	Amethyst	Small quantities of manganese
Rose or pink	Rose quartz	Small quantities of titanium
Scarlet red or vermillion	Mercuric sulfide	Mercuric sulfide

cups in a pan of cold water and heat the pan until the pieces in the different cups are soft. Ask the children to guess why the samples that require heating are best prepared in very small pieces. (More of the surfaces will be exposed when they are heated. The pieces will heat faster and the time required to extract the pigments will be reduced.) If pigments are not removed by this process, try this method. Add about one tablespoonful of denatured alcohol (rubbing alcohol) and stir the contents of the cups until the alcohol is mixed with the water. (See Table 30.5.) Over low heat, continue the cooking process until the liquid in the cup becomes a shade darker than the pigment sample. Some of the parts of the plant will require more heating than others (bark, wax-coated leaves, and parts that have thick membranes). Add alcohol at 5-minute intervals until the pigment removal process is completed. Leaves and bark will become several shades lighter but may not whiten.

Strain the contents of each cup through a piece of nylon stocking into a glass container. Pour the wet pigment back into the cup and heat it in a pan of water until it is several shades darker than the color of the sample from which it was extracted. Store the liquids in sealed glass containers. Label each container.

Table 30.4

PIGMENTS CAUSE SOME SHELLS TO BE COLORED

Color	Shell Name
Red	Rose Petal Tellin, Blood-Mouth Conch
Yellow	Coquina
Green	Pearly Oyster, Florida Worm Shell
Blue	Dipper Shell, Zambo Murex (royal purple dye once obtained from snail's body)
Violet	Leafy Rock Oyster

3. Observe and compare the wet plant pigment in sunlight, in the beam of light from a slide projector, and in a dimly lighted room.

4. Let the class use some of the extracted plant pigments either to dye or to paint two-inch squares of white tissue paper. If children are given the opportunity to experiment, they can discover for themselves which of the liquid pigments can be used as both dyes and paints and which ones can be used only for paints. Help pupils keep careful records of their experiments so they can use them to make tentative conclusions regarding some of the differences between dyes and paints. Experiment with the optimum amount of time needed to dye the tissue paper and the number of coats of paint required to apply a thin coat of paint to the tissue paper. (For best results, the paper should not be too intensely colored.)

When the dyed and painted pieces of tissue paper are dry, mount one of each of the different colors of pigmented papers in ready-mounts. Also, mount one piece of tissue paper that has not been colored to use as a control slide.

First, project the control slide on the screen and observe the result. (The fibers in the paper produce the sensation of gray.) Why? [The fibers absorb some of each of the colors in white light. More of the light is passing through the spaces (holes) between the fibers than is being transmitted through the fibers. The smaller amount of light that is transmitted through the fibers causes the sensation of gray.]

Project each of the colored slides on the screen, observe, and record the results. From their records and their observations of the colored slides, the pupils should be able to make tentative conclusions similar to these: (1) The color projected on the screen is a lighter shade than the colored slide. (2) The projected color is a combination of gray and the pigment color. (3) The pieces of tissue paper that were dyed in the shortest period of time transmit the most intense hues of the different pigments. (4) The tissue paper that was dyed in the shortest period of time is more nearly transparent to light than the ones that remained in the dye overnight and the ones that were painted.

5. Help the children to enlarge their concepts of color by observing the colors of light that are transmitted through their collection of slides made with natural pigments. See Chap. 29, Inquiry 7 for the directions given for using a prism to analyze the colors of light that pass through a colored slide. If the pigment used was not too concentrated, each dyed and painted slide will transmit enough light to obtain a spectrum in which the main colors of light transmitted will be *dominant.* The light passing through each slide will be composed of at least two and often three colors of light.

6. Pupils should be able to draw qualified and tentative conclusions similar to the following from the experiences they have had with plant pigments:

1. Some pigments can be used as dyes.
2. The pigments that could not be used as dye could be used as paint to coat the surface of the tissue fibers.
3. The pigments used as dyes transmitted more light than those used as paints.
4. The pigments used as dyes seemed to *penatrate* through the fibers in the paper.
5. The pigments used as paints seemed to *coat* the outer surface of the tissue paper fibers.
6. The tested pigments transmitted either two or three different dominant colors of light.
7. The pigments seemed to transmit a mixture or combination of two or more colors of light.

7. Some children may wish to make colorfast dyes from natural pigments and dye a piece of cloth. Others may enjoy making permanent paint from lamp black. Pigments can be extracted from berries, spinach, and swiss chard. Colorfast dye from natural pigments can be made from the following receipe: 1 quart of berries or finely chopped leaves, 2 quarts of water, and 1 ounce of powdered alum. (Alum can be obtained from a drugstore.) Cook berries or leaves in water until they are soft; mash and strain. Add alum, the *mordant* or *dye fixative.* Place the dye bath over heat and let it simmer gently throughout the dyeing process. Wet one pound of white cotton cloth in clear water. Wring excess water from cloth and place the cloth in the dye bath. Stir material in dye bath with either a glass rod or a wooden dowel rod until cloth is one shade darker than the desired color. Remove cloth with stirring rod and place the cloth in either a glass or enamel container until it is cool enough to handle. Have the child who is going to wring the excess dye and water from the cloth wear rubber gloves and a plastic apron to prevent the dye from staining his hands and clothing. Wring excess liquid from cloth and rinse it several times in clear water. Hang dyed cloth on a line to dry. Protect floor under line from stains by placing a layer of wax paper on floor and stacking several layers of newspapers on top of the wax paper.

The pupils who prepare and use flat black and glossy black (enamel) paint should observe precautions similar to those used by the children who worked with the dyes. Tabletops should be covered with newspapers. The materials with which they are working should be placed on a metal tray; and the stirring rods with which they mix the paint should be composed of a substance that can be either cleaned or discarded. A large-mouthed glass jar with a screw type cover can be used for both mixing and storing the paint.

Lamp black, carbon formed during the burning process of kerosene, wax, wood, and other fuels is a good pigment for making black paint. The carbon can be collected by holding a *pyrex dish* above the flame of a candle. When a thick film of carbon forms on the container, remove the dish from the flame. Hold the dish over a piece of wax paper and scrape the carbon from the container onto the wax paper. Pour the carbon particles into the paint mixing jar. Put a few drops of *linseed oil* into the jar and mix the carbon and the oil thoroughly. Add enough *turpentine* to the mixture to make it thin enough to apply with a paint brush. Pour one-half of this mixture into a second large-mouthed jar. Label the first jar "*flat black paint*" and cover it tightly.

Add a few drops of clear varnish to the "flat black paint" in the second jar. Label it "*glossy black*" or "*black enamel.*"

Saw a small piece of wood into three pieces. Prepare the surfaces of each of the pieces for painting by sanding them until they are smooth. Remove any sawdust that may be clinging to the wood with a soft cloth. Paint one piece with the flat black paint. Paint the second piece with the black enamel paint and keep the third piece as a control. When the paint is dry, have the class observe the difference between the two painted surfaces.

8. Have the children use reference books to find information regarding some early and recent sources of natural pigments. Help the class increase their library skills by making them aware of *key words*. The italicized words (in this and the two paragraphs following) are the key words the children should use in their search for information. The following information can be found in unabridged dictionaries, encyclopedias, and books on rocks, minerals, insects, and shells. Red and yellow *ochres* were used by the Indians for war paint. In colonial days, both Indian and white women used butternuts, walnuts, roots, and berries to obtain pigments for *dyeing* clothing. In some parts of the world, natural pigments are still being used for *dyes.*

The oldest known dye is *indigo*. This deep purple dye was formerly obtained from the indigo plant that is native to India. Purple pigments for dyeing fabrics were also obtained from the bodies of such *molluscs* as the *Murex. Carmine* red pigments were extracted from the bodies of *Cochineal* beetles, which are native to Mexico. Before the 20th century, dyes made from natural pigments were so expensive that only royalty and wealthy people could afford to purchase fabrics dyed purple (from the indigo plant or Murex mollusc), carmine red (from Cochineal beetles), and vermillion red (from mercuric sulfide).

Shortly after World War I, *aniline dyes* were being manufactured in large quantities from *coal tar*. Since that time, more than a thousand different inexpensive dyes have been made. These dyes have made it possible for many more people to own colored fabrics and clothing.

9. Observe the color of shells in white light. Colorless shells that have (1) a *pearly luster* (like mother-of-pearl buttons) or are (2) *iridescent* (transmit interchanging rainbow colors, like the abalone shell) lack natural pigments. Many shells, however, do contain pigments and, in a

Table 30.5

HOW TO EXTRACT PIGMENTS FROM PLANT CELLS

Plant Part	Process
1. *Bark*	Shred, boil in water for several hours, then boil in alcohol and water. Strain.
2. *Flowers*	Select nonvariegated petals, boil in alcohol and water. Strain.
3. *Fruits*	
Citrus	Juice: Concentrate juice by boiling or by evaporation. Strain. Skin: Grate, boil in water, and then boil in alcohol and water. Strain.
Berries	Crush, concentrate by boiling. Strain.
Tomatoes	Crush, concentrate by boiling. Strain.
4. *Leaves*	Shred or crush, cook until soft, boil in alcohol and water. Strain. Pigments are easier to extract from broad leaves that have thin membranes and are not coated with wax.
5. *Roots*	
Beets, carrots	Cut into small pieces, cook until tender. Strain. Can also be ground in a food chopper and strained.
6. *Seeds, hulls, or membranes*	Select brightly colored seeds. Boil *large* seeds and nut meats until membranes burst. Remove and boil skins. Boil in alcohol and water and strain. *Small* seeds can be processed without removing the skins or membranes. A cupful of small seeds will make about one tablespoonful of dye.
7. *Stems*	
Asparagus, rhubarb	Select fleshy stems. Shred or crush, cook until soft, boil in alcohol and water. Strain.

large collection of shells, the class will be able to see a full range of colors from red to violet. Also, ask the children to consult books on shells to find the names of shells that are colored red, yellow, green, blue, and violet (see Table 30.5).

Some of the pupils may also like to find the names of shells that contain a mixture of pigments and reflect such colors as brown, orange, red brown, yellow brown, green brown, pink lavender, and so on.

10. Plan to take a trip to a museum to see the wide variety of pigments present in its collection of bird and animal coverings. Explain to the children, while they are observing these collections, that the blue they see in the feathers of such birds as the bluebird and the bluejay and the metallic blues and iridescent colors in some bird feathers and in the bodies and wings of some insects are *not caused by the presence of pigments.*

2. Where are pigments located in green plants? What causes the fruits and leaves of plants to change colors?

Pupil activities

1. Discover the basic pigments that are usually present in green leaves. (See Table 30.6.) Yellow compounds called carotene are always present in green leaves. Try this experiment. Cover the same part of the upper and lower side of a geranium leaf with black construction paper. Seal the pieces of paper together. Wait for several days and then remove the black paper. Results? (The covered part of the leaf is yellow.)

Observe the color changes that occur in older leaves on house plants, trees, and shrubs. Remove several of these yellow leaves. Note how easily they are removed. Also, observe the *leaf scars* on the stem or twig where the leaves were attached. Examine the thin, corky layer called the *abscission layer*, which has grown between the leaf stem (petiole) and the twig. As this membrane grows, it cuts off the water supply to the leaf, the chlorophyll in the leaf breaks down, and the yellow pigment becomes visible. Try blowing against some of the yellow leaf blades. They frequently fall when the slightest breeze blows against them.

Pull several green leaves from the same plant from which the yellow leaves were obtained. Observe the following: (1) they are harder to remove; (2) sap oozes from the openings in the leaf scar. No sap oozed when the yellow leaves were removed. Speculate about what would happen if an abscission layer did not form between the petiole and the twig. (Valuable mineral nutrients and food, which are in solution in the plant sap, would be lost. Water would evaporate through the openings in the leaf scars. Disease-causing bacteria and fungi could enter the plant through these openings.)

2. Germinate some large seeds, such as lima or kidney beans, in a dark place. After several days, observe the color of the growing embryo. Take equal numbers of the germinating seeds and use them to discover whether there is a difference in the color of the seedlings when they are grown in varying amounts of sunlight.

3. Look for information about the different pigments that are present in the tissues of green plants (see Table 30.6).

4. Bring green fruits to school and observe them change color as they ripen. Such fruits as tomatoes, pumpkins, bananas, oranges, mangoes, and papayas are good for this experiment. Discuss with the children why these fruits change colors. Why couldn't the pigment color of the ripened fruit be seen *before* the chlorophyll decomposed? Record the children's answers to this second question and have them check their answers with the results of the following experiments.

5. Select two pupils to plan and do this "surprise" experiment. The experiment should be prepared at a time when the two children can work alone in the classroom and can also check the conditions under which the best results can be obtained. The purpose of the experiment is to find out why only one pigment (chlorophyll) can be seen, when at least two (most frequently chlorophyll and one or more carotenes or xanthophylls) are present. Have the two children tear one sheet of green construction paper and one-tenth of a sheet of yellow construction paper into tiny pieces. Be sure that they understand that the green paper represents chlorophyll and the yellow piece represents either one of the carotene or one of the xanthophyll compounds, which are present in the parts of a plant that turn yellow, orange, or red orange when chlorophyll decomposes.

Scatter evenly on a tray first the yellow pieces of paper and then the green ones. Then have the children *find and measure* the distance from the tray at which they can see only the green pieces of paper. When the two pupils *show* this experiment, they should have their classmates *stand at the same* distance at which they stood when they saw only the green pieces of paper. After each child in the class has observed and reported that he sees only green paper on the tray, have each one take a close-up view. The children can now see that there are really two colors of paper on the tray. Make certain that the children understand that the green pieces of paper hide the yellow ones from their view because so much more green light than yellow light is being reflected to their eyes.

Have the class experiment also with different proportions of the colors—green and yellow—to find out what happens. Let the pupils scatter evenly a *known number* of green and yellow wax crayon dots on a piece of paper. Will the color of the larger number of dots dominate over the color of the smaller number of dots? (It will.)

6. Ask the children to bring again several pieces of a kind of fruit that will ripen indoors. Let the class find out whether the *intensity* of the color of the ripened fruit is affected by the amount of light it absorbs. (The color of the piece of fruit ripened in bright sunlight will be more intense than those pieces ripened in dim light or darkness.)

Help the class to apply the learnings in Chap. 29, Inquiry 3 to aid them in stating why the pigment color of fruit that is tree- or vine-ripened in sunlight is more intense than the pigment color of the same kind of fruit ripened artificially in darkness. (The pigment of an opaque object is the color of the light that it reflects.) Other colors in light are absorbed and changed into heat energy. Green fruit *reflects* more of the green wave lengths in light and *absorbs* more of the red and blue wave lengths. As the chlorophyll (green pigment) decomposes in the natural ripening process, most kinds of sun-ripening fruit will reflect less and less green light. The additional light energy from the green wave lengths that are now being absorbed by the fruit causes an increase in the chemical activity, which produces increased amounts of carotene and xanthophyll pigments. This may explain why vine-ripened tomatoes are redder than artificially ripened ones.

7. Apply the learnings from the experiment with the changes of color of ripening fruit to the change of color in autumn leaves. Help the children understand that chlorophyll decomposes when *temperatures are either too high or too low.* Chlorophyll is not manufactured in green plants when the temperatures are much below 55°F or much above 80°F. In whatever part of the world children live, they can find evidences that the intensity of the green pigment, chlorophyll, is affected by extremes in temperature.

Although the most beautiful displays of autumn colors in leaves are seen in the northeastern part of North America, less extreme changes in leaf color are worldwide. Most green leaves change color *before* they fall from the plants. Help the children develop the concept that the *right kind of climate, soils, and plants* are necessary to produce the blaze of autumn colors from yellow, gold, and brown to reds and purples. The northeastern part of the United States and Canada is the land of the mixed deciduous forests, the land of the beeches, hickories, birches, oaks, and maples and the land that has a so-called "Indian Summer."

Indian Summer weather occurs during the months of September and October. The cool nights at this time of the year cause the chemical breakdown of the chlorophyll in the leaves. At these temperatures no more chlorophyll is produced; hence, the carotene pigments that have been present in the leaves all during the growing season are now visible. The most vivid reds and purples appear after one or more sudden cold snaps (wide variations in day and night temperatures). These sudden changes in temperature together with *dry, sunny days* are believed to cause the chemical activities to increase the amount of anthocyanins present in the cell sap.

With the exception of a few purple and bronze-leafed plants, such as certain kinds of crotons, coleuses, and begonias, the presence of anthocyanins is not revealed until after the chlorophyll disappears. The strong reds and purples and the mottlings of yellows and reds in autumn leaves are caused by the masking out of the carotenes. Combinations of purple, purple reds, orange, and true reds produce all of the varied colors found in autumn leaves and in the skins of autumn fruits as well. Leaves of clear yellow, such as are found in some hard maples, have no purple pigment in the cell sap. Leaves of strong red are colored by a combination of purple sap pigment (anthocyanins) and red carotene. The changes in leaf color that can be produced by carotene com-

Table 30.6

COMMON PIGMENTS FOUND IN GREEN PLANTS AND THEIR IMPORTANCE

Name of Pigment and Class	Class 1 Chlorophyll	Class 2 Carotene Compounds (more than 60 known different kinds)		Class 3 Anthocyanin Compounds	Class 4 Tannins
		Subclass A Carotenes	Subclass B Xanthophylls		
Color of Pigment	Green	Lemon yellow to orange	Yellow orange to tomato red	Palest pink to blue and purple	Brown
Where found	Inside plant cells in bodies called *plastids.*	Inside plant cells bodies called *plastids.*		Dissolved in cell *sap* in leaves, stems, some roots, some fruits, and some flowers.	In cell *walls* in various parts of the plant. Can be seen in the bruised or dying tissue of most plants.
	In *chloroplasts* (plastids that contain the green pigment called chlorophyll).	In *chromoplasts* (plastids that contain pigments).			
	Chloroplasts occur in leaves, modified leaves, stems, young twigs, unripe fruits, and some ripe fruits.	Chromoplasts occur in leaves, modified leaves, stems, some roots (carrots), unripe fruits, and ripe fruits.			
	Some examples: gooseberries, figs, green gage plums; such apples as Greenings and Russets; such squashes as Acorn, Hubbard, and Buttercup; green peas, and green string beans.	Some examples: pumpkins, yellow squashes, papayas, mangoes, cantaloupes, bananas, citrus fruits; and such apples as Transparents and Golden Delicious.	Some examples: tomatoes, radishes, peaches, red cherries.	Some examples: red beets, red onions, red cabbage, purple grapes, black sweet cherries, strawberries, blackberries, raspberries, and watermelons.	Some examples: bark of sumacs, hemlock, sea grape, fiddle leaf fig, and oaks are rich sources of tannin. Most plant tissue contains some tannin.

Importance of pigments	Essential for *photosynthesis* (the chemical change by which green plants manufacture carbohydrates).	May be important for phototropism (the movement of plants toward and away from light).		The function in plants of most of these compounds is unknown.	Function in plants is unknown.
	Absorbs primarily from the red and blue wave lengths of light the *energy needed* for photosynthesis.	Absorbs and utilizes certain wave lengths of light for part of the *heat energy* needed for photosynthesis.		A *light-sensitive* blue pigment, *phytochrome,* which is present in all green plants is a "triggering mechanism" for germination, growth, and flowering. Even though this pigment is present in too small amounts to be seen, it controls the growth activities of many green plants. This discovery has made it possible for nurseries to force annuals to bloom at any time of the year and to control the heighth at which the blossoms develop. The pigment can also be sprayed on the seed or plant and artificial lights are used to control the length of day.	Tannins are used for the tanning of leather.
	Acts as an *enzyme* which *accelerates* photosynthesis.		A source for Vitamin A A carotene called *lutein* causes the yellow color in egg yolk and butterfat. The lutein in plants eaten by animals that produce eggs and butter fats is not chemically changed by their digestive tracts.		

pounds in the cells and anthocyanin in the cell sap are almost endless.

Make certain that the children understand that it is *not frost* at 32°F but dry, warm, sunny days and cold night temperatures, which fall to about 45 degrees Fahrenheit, that cause the vivid colors of autumn leaves. The riotous colors produced during Indian Summer weather do not appear in leaves, even in the lands of the mixed deciduous forests, if the weather is mild and rainy.

If the pupils live in regions where such trees as beeches, maples, hickories, and oaks grow, take them on field trips in the autumn to see the changes that occur in the color of the leaves on both trees and shrubs. Field trips should also be taken in the early spring when the leaves are just beginning to open. After they return from each of these trips, help them to make a record of their observations. Their record could be organized like this one.

A RECORD OF THE COLORS OF LEAVES SEEN IN THE SPRING AND AUTUMN

1. The leaves of some trees and shrubs turn yellow in autumn. (Willows, birches, beeches, elms, hickories, poplars, some kinds of maples, forsythia, spirea, syringa, and raspberry.)
2. The leaves of some trees and shrubs turn red in the autumn. (Red maple, scarlet oak, red oak, white oak, dogwood, tulip tree, sassafras, sweet gum, black gum or tupelo tree, wild cherry, sumac, blueberry, blackberry, poison oak, poison sumac, and poison ivy.)
3. The leaves of some trees turn golden brown in the autumn (Redbud, and such oaks as swamp white oak, chinquapin, chestnut, and post.)
4. A short time after the leaves fall from the plant, they turn brown.
5. The leaves of most broad-leaved deciduous trees and shrubs have the same basic colors in the spring as they do in the autumn. The spring colors of leaves are less noticeable because the leaves are not full grown and the pigment colors are less intense in the spring of the year. (The brown and gold colors of some oak leaves and the mottling of red, yellow, and orange of some maples is not visible in spring.)

Pupil activities

1. *Discuss why chlorophyll is important to* green plants. See Chap. 13.

2. *Read and discuss why the carotene and anthocyanin pigments in some flowers are important for reproduction.*

3. Why are pigments important to plants?

The colors of light reflected by the carotene and anthocyanin pigments present in some flowers are important for reproduction. All flowering plants must be pollinated to produce fertile seed. Some flowering plants pollinate themselves, others are pollinated by the wind, and still others are pollinated by animals. Animal-pollinated plants produce showy flowers that are either pigmented and scented or both. The different pigments present in flowers attract different kinds of animals that are searching for food. Animals can see certain colors that people cannot see; likewise, people also can see certain colors animals cannot see.

Insects are the most important pollinators of flowering plants. The color of a flower seems to be the primary attractor for both bees and wasps. The bees' eyes are more sensitive to white (a mixture of colors) and to blue and ultra violet light than they are to the longer wave lengths (red and yellow). Red flowers appear to be black to bees. Because bees do not see red, they do not pollinate red flowers. Neither can they distinguish the difference between lemon yellow, orange, and green flowers. Blossoms that have these colors appear to be the same to all bees but they do pollinate them. Have the children guess what the colors lemon yellow, orange, and green appear to be to the bees. (Gray. Some of each color in white light is absorbed and some is reflected.)

However, bees can distinguish the difference between the numerous combinations of yellow, yellow green, blue, and violet. Because their eyes are sensitive to ultra violet, they can also see many blossoms that appear muted to people but to bees they glow with beautiful ultra violet light.

The fragrance of a flower seems to be the primary attraction for such insects as ants, butterflies, and moths. Butterflies and moths have such a keen sense of smell that they can detect the odor of flowers that are a mile away from them. The intensity of light reflected by flowers may also be a factor, since moths are attracted to flowers such as the night-blooming cereus.

3. The flowering plants most commonly pollinated by animals are plants that produce flowers that attract insects. Ask the pupils to name some red flowers that grow in the fields and forests.

There are not many. (The redbud, or Judas tree, the cardinal flower, and red dogwood are some of the most common ones.) Also, have the children list solid red flowers that bloom in gardens and nurseries. (The poinsettia flower is not red. The leaves (modified leaves called bracts) that surround the true flowers are red. Varieties of carnations, roses, peonies, salvia, zinnias, poppies, sweet peas, sweet williams, and ixora are a few of the solid red flowers.) Find out whether the pupils can name some of the animals that pollinate these red blossoms. (Ants, butterflies, and hummingbirds.)

Finally, ask the class to list some white, yellow, and yellow green flowers. After the pupils have named a few of these flowers, they will realize that most of the flowers they know belong in a color group.

Emphasize the fact that *animals do not knowingly* carry pollen from one flower to another. It is done *accidentally*. Animal pollinators are searching for food in the flower. The pollen clings to their bodies, and as these animals move from one flower to another the pollen rubs off.

4. Ask the pupils to bring flowers to school. Let the children use magnifying glasses to examine the pollen attached to the pollen holder (anther). (See Chap. 14, Inquiry 3.) Let one of the children hold one or more flowers over a piece of white paper, shake some of the pollen on the paper, and examine these pollen grains with a magnifying glass. Ask the children to guess the probable number of pollen grains produced by a single flower. (The number will vary with the size and quantity of stamens. A safe guess would be hundreds or even thousands of them.) Have the pupils touch the pollen grains and observe that the pollen clings to their fingers. Pollen also clings to the bodies of animals that rub against the pollen grains, which are attached to the pollen holders (anthers) in the flower.

Discuss with the class the relationship between the *quantity of pollen* produced by flowering plants and their *survival*. (The quantity produced makes it more likely that some of the pollen will reach another flower of the same species and that this flower will produce fertile seed.)

Also, make certain that the children understand that plants *do not knowingly produce large quantities of pollen*. The production of large quantities of pollen is one of the *inherited characteristics* of flowering plants that has made it possible for them to survive.

5. Develop an awareness in the pupils that very little is known about the value of pigments to the plants that produce them. (See Table 30.6.) New discoveries are being made each year. Encourage the children to watch for the reports of these discoveries in current literature and on television and radio.

4. Why are pigments important to animals?

Pupil activities

1. Discuss some of the pupils' experiences that provide evidence that protective coloration in animals is a means of survival. The children will have had a number of experiences that illustrate the importance of different colors and patterns of color in preventing animals from being seen by their predators. The color of a female bird's feathers is usually more subdued than the color of a male bird's feathers. Most female birds incubate their eggs. A nesting bird is very difficult to see because its colors blend with its nesting place. The subdued colors of rabbits, squirrels, chipmunks, deer, and many other kinds of mammals make them difficult to see. The environmental colors of grasshoppers, crickets, caterpillars, and many other kinds of insects make it difficult for preying animals to find them.

2. The colors and markings of some animals serve as warning devices to their predators. Patterns of yellow and black are predominant among the bees, wasps, and some kinds of butterflies and moth caterpillars. Birds usually avoid these insects because they have an unappetizing taste or an unpleasant sting, or both. Birds *do not have* a built-in instinct that causes them to avoid these colors. *Each* bird *must learn to avoid them* by having at least one disagreeable experience. This one disagreeable experience teaches a bird to avoid other animals with similar color markings even though some of these animals are palatable. Birds learn that monarch butterflies have a disagreeable odor and taste. More of the palatable viceroy butterflies survive because their species inherits color markings that are similar to those of monarch butterflies. Make certain that the children understand that *animals do not decide to protect* themselves by mimicking other

animals that have unpleasant odors, tastes, and stings. The different colors and markings of animals are *inherited* and are adaptations that result in or permit survival.

Table 30.7

SOME EXAMPLES OF INSECTS THAT RESEMBLE THE COLORING OF OTHER ANIMALS AND THE COLORS OF THE PLACES WHERE THEY FEED AND REST

What the Colors Resemble	Insects
Bees	Robber fly family, one species of Sphinx moth (*Hemaris thysbe*).
Eyes of vertebrates	Adult moths: Io, Luna, and Polyphemus. Adult butterflies: Buckeye, Pearly eye, and Common Woodnymph.
Bark	Catocala moth family; one species of adult geometrid or measuring worm; the mottled stinkbug. Most species of moths that rest on the bark of trees during the daytime have color markings that closely resemble bark.
Leaves and stems	Dead leaves: The mourning cloak butterfly resembles the leaves of the black willow in the spring of the year; cocoons of such moths as prometheus and polyphemus. Green leaves: One species of crescent butterflies (*Grapto faunus*); leaf hoppers and katydids. The larvae of most butterflies and moths that feed on leaves closely resemble the color markings of the food plant.
Twigs and branches	Walking sticks, mantises, measuring worm larvae (geometrids); cocoon of cecropia moth.
Ground covering	Beetles, grasshoppers, crickets, and ants.
Transparent wings that match any background	Male peach borer; sphinx moth (*H. thysbe*); one of the Psychid or Bagworm moths, cicadas, dragon flies, and damsel flies.

3. Appearing inedible is another adaptation that helps some kinds of insects to survive. Some kinds of insects have tattered wings that resemble dead leaves; others have wings that look like lichen-covered bark; still others have transparent wings that take on the shape and color of the background on which they are either resting or feeding. (See Table 30.7.)

4. One kind of unusual color marking, seen on mantises and some kinds of beetles, butterflies, and moths, consists of bright patterns that resemble the eyes of vertebrate animals. These eye spots are often located on the portions of the insect's body that are concealed while it is feeding or resting and are displayed suddenly when the insect is attacked. Eye spots may also afford protection for the newly hatched insect during the period in which its wings are still hardening.

Ask the children to locate information similar to that listed in Table 30.7. Also, take them on a field trip to look for examples of protective coloration.

5. What are some of the explanations for the color sensations produced by things that lack pigments?

See Chap. 33, Inquiry 12 for understandings of *wave interference* and *diffraction*. These understandings are basic and necessary for understanding how the color sensations from some objects occur because their structure produces color by the interference and diffraction of light waves. Before continuing with this question, the pupils need to have the experiences in Chap. 33, Inquiry 9.

Children have enjoyed and observed the *iridescence* (play of rainbow colors) of soap bubbles. Some pupils may have wondered what causes the colors. Some experiences with iridescence follow.

Pupil activities

1. Wave Interference from Reflected Light. Ask the children to bring soap bubble blowers to school. Soda straws and the wooden spools on which sewing thread is purchased make excellent bubble blowers. Give the class the opportunity to watch the bubbles form and to compare the play of colors on different *sized* bubbles and under a *variety of lighting conditions*. Have them blow bubbles in darkness, in semidarkness, in bright sunlight, and in a room lighted by overhead lights. Also, let the light strike the bubbles *from different angles.* Ask them to compare the iridescence on bubbles that are formed quickly with big strong puffs of air with the iridescence of those formed slowly with small gentle puffs. Under what conditions are the best displays of colors produced? (When either sunlight or lamp light strikes the bubbles at an angle, and when large bubbles are formed slowly.)

Partially fill a container with water. Add either a liquid soap or a liquid detergent to the water and whip the mixture with an egg beater until a great many large bubbles pile up on the surface. Ask the class what beating adds to the mixture? (Air.) Vary the lighting conditions and the angle at which the light strikes the bubbles and observe the difference in the iridescent display. Bring from home several of the clear glass balls that are used as Christmas tree ornaments. Tie the glass balls on a string and let them dangle in the light. These balls will also be iridescent. Pour some water in a pan and place drops of salad oil on the surface. Note the iridescence.

Three conditions that cause the iridescence seen in each of the previous experiences are very evident. Find out whether the pupils realize that iridescence occurred when there was (1) a source of white light, (2) air (could be any colorless gas), and (3) a *transparent material.* Another condition caused the iridescence: (4) irregularities in the surface of the material or variations in the thickness of the material. Some of the following experiences should help to make this condition for iridescence evident to pupils.

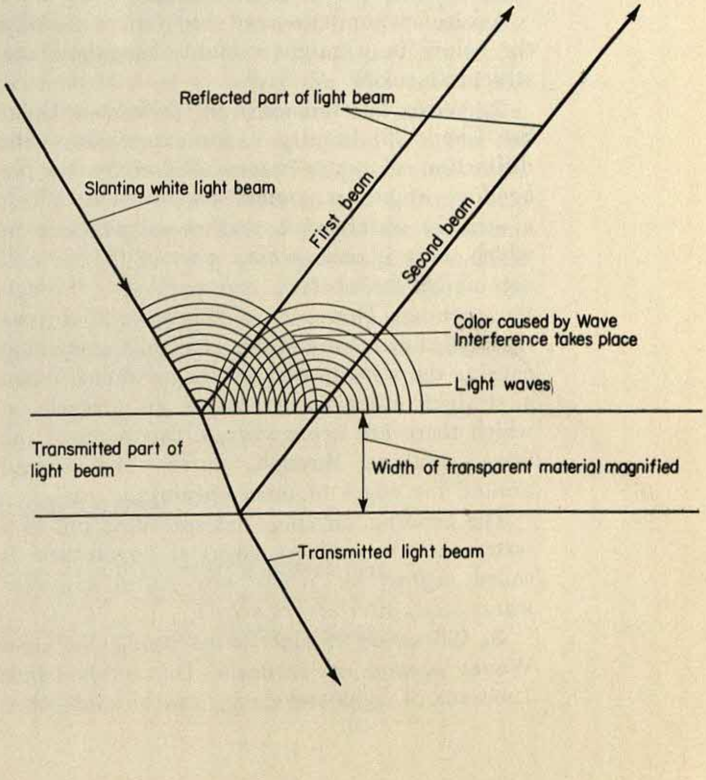
Obtain a small piece of plate glass, which has at least one smooth polished edge. If all edges are polished, break the glass so that there are some irregular edges. Have the pupils look at and compare the smooth and irregular edges. (The irregular broken edges will be iridescent; the smooth polished edges will not be.)

Scatter small pieces of wrinkled, transparent tape between two pieces of glass and tape the two pieces of glass together. Hold the glass "sandwich" so that the light strikes it from an angle. Make sure that the pupils are aware that the iridescence they see is caused by the irregularities in the surface of the wrinkled tape.

Dip a small loop made of thin wire in a mixture of soap or detergent and water. Remove from the liquid. Notice the soap or detergent film in the loop. See the iridescence. When the loop is held vertically, what does gravity do to the film in it? (The film drains toward the bottom. It grows thicker toward the bottom.) Where is the iridescence? (Where the film thickness varies.) Iridescence is caused by the different thickness of the film in different parts of the loop. What evidence is there that the soap or detergent film of a soap bubble has different thicknesses in different places? (The bubble breaks where the film becomes too thin.)

Iridescent effects are caused by light waves reflected from *transparent materials.* When white light strikes the first surface of a transparent material, part of the light is reflected and part is transmitted. When the transmitted part reaches the second surface, part of it, too, is reflected and part of it is transmitted (see Fig. 30.1). Be sure the pupils realize that *from one light beam* the transparent material produces *two beams of reflected light.* Where the light *waves* in these *two reflected beams meet,* wave interference occurs. (See Fig. 30.1.) When two or

Fig. 30.1 Iridescence results where the light waves in the two reflected light beams interfere.


Reflected part of light beam
Slanting white light beam
First beam
Second beam
Color caused by Wave Interference takes place
Light waves
Transmitted part of light beam
Width of transparent material magnified
Transmitted light beam

more waves interfere with each other, they sometimes *reinforce* each other and sometimes *block* and *cancel* each other. See Chap. 33, Inquiry 9. When interference occurs in certain colors (wave lengths) in white light, some colors are reinforced and some are blocked. It is the interference that causes iridescence in some transparent materials.

Develop the concept that iridescence is caused by the structure of things (*the film* of a soap bubble, the *oil film* on water, the *glass skin* of the Christmas ornament, the *irregular broken edge* of the plate glass, *the wrinkled surface* of the transparent tape). For this reason, the colors of iridescence are called *structural colors.*

The wings and bodies of some insects, the feathers of some birds, the linings of some shells, and the scales of some fish are iridescent. Their iridescence is caused by *their structure.* Where it is possible to examine some of these animal structures, have the children check them for transparency (also transparent coatings and linings), surface irregularities, and variable thicknesses. Discuss why structure can cause the interference of light waves. (If part of the light beam that strikes a structure is reflected in two beams, the light waves in these two beams will cause interference and iridescence.)

Ask some pupils to read and report on why the colors in a rainbow and a moonbow are structural colors.

2. Wave Interference from Diffracted Light. See Chap. 35, Inquiry 9, for experiences with diffraction of water waves. *Diffraction is the bending of waves around an obstacle.* When a straight water wave reaches an obstacle in which there is *one opening,* part of the wave is cut off by the obstacle and part goes through the opening. That part of the wave that goes through is bent around the edges of the opening causing the wave to curve and spread out. When a straight water wave reaches an obstacle in which there are *two openings,* two parts of the wave continue through, curve, and spread around the edges of these openings.

The bending, curving, and spreading out of a water wave around the edges of an obstacle is called *diffraction.* Where *two diffracted water waves meet, interference occurs.*

3. Diffraction of Light Is the Bending of Light Waves Around an Obstacle. Diffraction bands (patterns of light and dark) can be seen when light (1) bends around the edges of obstacles, and (2) passes through *very small* openings in obstacles. When *diffracted waves of white light meet, interference occurs; and bands of colors, which are caused by the reinforcing and blocking of some colors (wave lengths), are added to the diffraction bands.*

Have the pupils take turns holding a long playing record edgeways to the light and observe the iridescent colors that appear to be streaming across the edges of the grooves in the record. Help them to understand that these colors are caused by interference, which occurs between the light waves that are diffracted by the edges and grooves of the record.

Darken the room. Place an electric lamp on a table either in the most distant part of the classroom or in a long dark corridor. Turn on the light. Let the pupils take turns holding a thin white handkerchief in front of their faces, squinting their eyes, and watching the play of rainbow colors (iridescence) that appears around the outer edges of the light beams that seem to be streaming from the lamp. The small threads (obstacles) in the handkerchief diffract the light waves. Interference between these diffracted waves causes some colors (wave lengths) to be reinforced and some to be blocked. Some of the pupils may want to try the handkerchief experiment at home where at night they can look through it at a more distant street light. They can see the interference effects caused by diffraction of the light as it passes through the small openings in the cloth. They can also see the same effects by looking through window screen at the street light.

The ribbed structure of the feathers of some birds and of the membranes of some insect wings diffracts light. The ribbed structure serves as an obstacle, and the small spaces between the ribs serve as very small openings that diffract light. When interference of the diffracted light waves occurs, iridescent colors are produced by the reinforcement or blocking of some waves. If possible, have the children examine the ribbed structure of the membranes of iridescent insect wings and iridescent bird feathers (grackle, hummingbird, and peacock).

Help the class discover that small particles in the atmosphere and in the feathers of some birds (bluebirds, bluejays) can also cause color sensations. Collect several small-mouthed bottles that can be stoppered, a shallow container of sand, four or five materials that can be burned safely in the classroom, and some samples of different kinds of dust. Some things which can be burned safely are: a candle, a large kitchen match, incense powder, an incense candle, a wooden splint, and a damp piece of paper towel or newspaper. The following samples of dust could be used: chalk dust, talcum powder, sweepings from the floor, sand, soil, and powdered clay. Fill one of the small-mouthed bottles with the smoke from a lighted candle and hold it in the light of a table lamp. Note the *blue* color. Blow or rinse the smoke out of the bottle and fill it with the smoke from one of the other materials to be burned. Continue until the children have seen the smoke from each of the materials. Ask the class to list the materials according to the color of smoke. From the samples listed under blue smoke, have them select the material (1) that yielded the *most intense shade of blue*, and (2) that yielded the *least intense shade of blue*. In separate bottles, again collect the smoke from those two. Have the children view them again in lamp light. If the children agree that these materials represent the most intense and least intense blue they can get from their samples, have them use smoke from these two sources in the next experiment.

Darken the room. Place a slide projector on the table and put the pan of sand about one foot in front of the lens of the projector. Light a candle and hold it at an angle over the pan of sand. The wax from the candle will drop on the sand. Adjust the angle of the candle until both the blue and black smoke from it can be seen in the beam of light from the projector. Also, test the two materials that yielded the different intensities of blue smoke. Ask the children to look carefully each time to see if they can locate any individual particles in the smoke from any of these materials. (They can see some in the black smoke. The particles that give blue light will be too small to see.)

Test each dust sample separately in the beam of light. Place the dust sample in a piece of cloth, tie the ends of the cloth together, and hold this bag of dust in front of the lens. Squeeze the bag like an accordion and observe the white particles of dust in the beam of light. Repeat this procedure with each dust sample. Discuss the results with the class. (In each case the particles will be visible and they will look white.) Also, ask the children to compare the differences in the size of the particles that cause the sensation of blue with the size of those that cause the sensation of white. (Particles that cause us to see blue light are smaller than the particles that cause us to see white light.) Have one of the pupils wipe off the lens in the projector with lens paper when the class has completed the experiment.

Apply the learning from the last experiment to the color sensations of blue that the pupils see when they look at a bluebird or a bluejay and when they look at the sky at different times of day and in different kinds of weather. (*Minute* particles and *minute* bubbles of air that are present or trapped in the feathers of these birds cause the *blue light* we see. Very *fine* particles of dust in the upper atmosphere also cause the sky to appear to be *blue*.) *Small particles* in the atmosphere tend to reflect the *blue* end of the spectrum. *Large particles* in the atmosphere, such as dust and water vapor, tend to reflect the *red* end of the spectrum. The greater thickness of the earth's atmosphere at the horizon also tends to emphasize the *red* end of the spectrum. This is why sunrises and sunsets have beautiful shades of red, orange, and yellow. Give the students the opportunity to apply their knowledge of color to the white, black, and different colors of clouds they see in the sky.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Many living things and some of the minerals in rocks contain pigments that transmit various colors of light. Not of all the colors we see are caused by the presence of pigments. When pigments penetrate the surface, the material is dyed. When pigments coat the surface, the material is painted.

2. There are more than a thousand different kinds of plant pigments. These basis, different kinds of pigments are classified into four groups: chlorophyll, carotenes, anthocyanins, and tannins. Carotenes are commonly found in most green leaves. Both carotenes and chlorophyll are found in cell bodies called plastids. These plastids are found in the cells that compose the plant tissues. Anthocyanins and tannins are in the cell sap and cell walls. Changes in chemical activities cause leaves to change colors. Differences in light and temperature cause changes in the chemical activities in leaves. The vivid coloration of leaves in autumn occurs primarily in the northeastern part of North America. In the other parts of the world that have autumn, people do not see the brilliantly colored autumn leaves because they do not have the right kind of broadleaved trees and shrubs and the right kind of climate. Frost does not cause leaves to change color. Warm, dry days and clear, cold nights cause the deep reds, scarlets, and purples to appear in some kinds of autumn leaves.

5. Both chlorophyll and carotene compounds absorb the light energy needed by green plants for photosynthesis. Chlorophyll enables plants to manufacture carbohydrates.

Most flowering plants must be pollinated to produce fertile seeds. Different pigment colors in the flowers and plants attract different kinds of animals when they are searching for food. Some flowering plants are self-pollinated; some are pollinated by the wind; others are pollinated by animals.

Insects are the most important animal pollinators. Animals do not knowingly pollinate flowers; they do it accidentally.

Bees do not see the same range of colors that people do. The bees' eyes are not sensitive to red. Red appears to be black to the bees' eyes. Such animals as ants, butterflies, birds, and bats pollinate red flowers. The bees' eyes are sensitive to white and light-colored flowers, and to flowers that reflect blue, violet, and ultraviolet light. Other than those that are wind pollinated, most common flowering plants are pollinated by insects.

The ability to produce large quantities of pollen is a means of survival for flowering plants. Flowering plants do not knowingly produce large quantities of pollen. The production of large quantities of pollen is an inherited characteristic of flowering plants.

Very little is known about the function of pigments in plants. New discoveries are being made each year.

6. Protective coloration is an adaptation that enables many different kinds of animals to survive. Most insects are protectively colored. The protective color markings of some kinds of insects resemble their resting and feeding places. The protective color markings of some other kinds of insects serve as warning devices to their predators.

Birds do not instinctively avoid animals that have certain colors and color markings. Birds first learn, by having a disagreeable experience, to avoid any animal that has color markings similar to the disagreeable one.

Animals do not decide to look like their environment, or a disagreeable animal, or something inedible. The different colors and color markings of animals are inherited.

7. Color properties that are not caused by pigments are called structural colors iridescence (display of rainbow colors), metallic blue, and blue green, and in some instances blue are structural colors. Structural colors are caused by materials that cause interference in light waves.

Iridescence is caused by interference of the different wave lengths present in white light. When the waves interfere, some are reinforced and some blocked or cancelled. The iridescent colors are the wave lengths (colors) that are reinforced. The missing colors in iridescence are the blocked or cancelled wave lengths (colors).

The iridescence of transparent materials, or of materials with transparent coatings or linings is caused by interference of reflected light waves. The iridescence seen on opaque materials is caused by interference of diffracted light waves. Both reflected light waves and diffracted light waves can cause interference.

The interference of light waves causes the iridescence seen on thin films of transparent materials, on the bodies and wings of some insects, in some shells, in the feathers of some birds, and on some fish scales. Interference of light waves also causes the iridescence seen in the ridged structure in the feathers of some birds and in the membranes of some insect wings.

The blue of sky, smoke, feathers, and eyes is a structural color. The structure of the object or very small particles of "dust," water vapor, and even very small bubbles of air trapped in the object cause the light waves that reach the eye to be predominantly blue.

Variations in the structure of things such as size, shape, transparency, thickness, surface irregularities, and layers cause the color variations produced by objects that lack pigments.

Chapter Thirty-One

Changing the Apparent Size of Objects

INQUIRY

1. What things are used to change the apparent size of objects?

1. What things are used to change the apparent size of objects?

Ask the children if they know the names of some things that can be used to make an object *seem to change its size.* They should be able to name magnifying glasses, field glasses, microscopes, telescopes, and microprojectors, film viewers and projectors, eyeglasses, and curved mirrors.

Have the children help to collect an equal number of magnifying glasses, flat (plane) microscope slides, and small sheets of colorless plastic or cellophane. The children can often contribute magnifiers of their own. Some children may have small plastic magnifiers in their pencil boxes. Be sure that the pupils realize that all of these materials are transparent. (See Chap. 28, Inquiry 9.) Have the children examine such objects as their fingertips, fingernails, a piece of paper, and a piece of cloth through each of the transparent materials. Which transparent materials make the objects look larger? (Magnifiers.) Which do not? (The glass microscope slides and the pieces of sheet plastic or cellophane.)

Ask the children to determine how the glass and plastic magnifiers differ from the glass microscope slides and pieces of plastic. (Magnifiers have *curved surfaces;* the other materials have *flat surfaces.*)

Ask the boys in the class to try to find enough colorless, transparent marbles in their marble collections for every member of the class to have one to use. Colored transparent marbles can also be used if the boys do not have enough colorless ones. Borrow enough colorless drinking glasses for each child. Loan each child a marble, a drinking glass, and a paper clip. Pour enough water into each tumbler to partially fill it. Tell the children to take long pencils from their desks and to hold them vertically behind their glasses of water. The pencils should touch the outsides of the tumblers and they should be longer than the tumblers are tall. Tell the pupils to look at their pencils *through their glasses of water* and *through the air above the glasses* (see Fig. 31.1.) What seems to happen to the size of that part of the pencil seen through the glass of water? (It seems larger. It is magnified.) What happens to the part seen through the air above the rim of the glass? (Nothing.) Next, ask the children to straighten out one end of a paper clip wire and look at it through the marble. (See Fig. 31.1.) What seems to happen to the size of the paper clip wire? (It seems larger through the glass marble than through the air.) Ask the children to compare these two new magnifiers with the glass and plastic ones used earlier. (The glass of water and the marble both have curved surfaces. The glass and plastic magnifiers have curved surfaces. The glass slide and the sheet plastic and cellophane do not have curved surfaces and they do not magnify.)

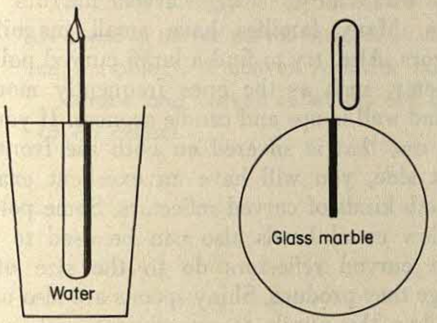


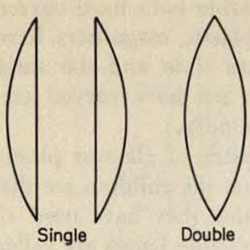
Fig. 31.1 What causes part of the pencil and part of the paper clip to look larger?

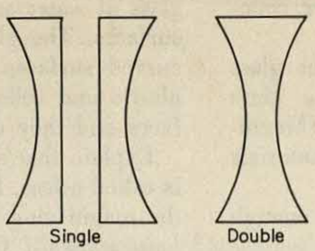
Explain that a curved piece of glass or plastic is called a *lens.* Be sure that the children see that the magnifying lenses which they have used all *bulge outward.* Outward bulging lenses are called *convex lenses.* A convex lens which bulges outward on one side is called a *single convex lens.* It is a *double convex lens* if it bulges outward on both sides (see Fig. 31.2.)

Borrow from the science supply room a collection of unframed lenses. Check to be sure you have lenses that make things *seem smaller* as well as lenses that make things look larger. Have the children test the lenses and decide which magnify and which diminish an object's apparent size.

Remind the children that they have learned that lenses are curved pieces of glass or plastic and that lenses that have a curved surface that bulges outward, *convex lenses, magnify the size of objects.* Ask them to examine the unframed lenses in the collection and to separate the ones that are either single convex or double convex. Use this selected assortment of convex lenses to reinforce the learning that convex lenses make things look larger.

When the pupils examine the remaining unframed lenses in the collection, ask, "Are these lenses curved pieces of glass? (Yes.) Do the curved surfaces bulge outward? (No.) How would you describe the curve?" (They curve inward.) Have the children look through the "inward curving" lenses to discover that they also seem to change the size of the object. (They make an object's size seem smaller. They seem to diminish its size.) Tell them that these lenses are called *concave* lenses. There are *single* and *double* concave lenses. Find out whether the collection of unframed lenses has both single and double concave lenses in it (see Fig. 31.3). It may not have double concave lenses in it, but a model of one could be made from a circular piece of modelling clay by pushing the front and back sides inward. Have the children cut large white paper models of side views of single and double concave and convex lenses for the bulletin board. Ask them to print the correct name on each of the models. Use these models to emphasize the fact that convex lenses are *thicker in the*





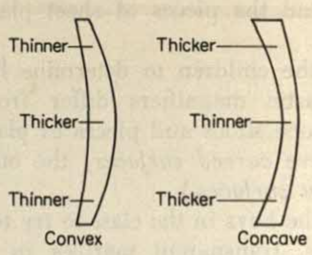


Fig. 31.2 (left) Single and double convex lenses.
Fig. 31.3 (center) Single and double concave lenses.
Fig. 31.4 (right) Eyeglass lenses (side views).

center and *thinner on the edges* and that concave lenses are *thinner in the center* and *thicker on the edges.*

Obtain a pair of eyeglasses which make print look larger and a pair which make print look smaller. Have the children determine whether the centers of the lenses are thicker or thinner than the edges. (The difference in the thickness between the center and the edge of the lenses may be too small to detect. The children should be able to deduce that the pair that makes print seem larger must have lenses that are *thicker* in the center than on the edges and that the pair that makes print look smaller must have lenses that are slightly *thinner* in the center than on the edges.)

Have one of the children cut side views of eyeglass lenses from white paper (see Fig. 31.4). Add these eyeglass lens patterns to the other models of lenses on the bulletin board.

Let the children feel the curved surfaces of the glass lenses in film viewers, in the front of slide, filmstrip and movie projectors, and in the eye piece of a microscope. Ask the class how these lenses are curved and to classify them. (They are curved outward. They are convex.) Open the cases of the projectors and let the children see the other kinds of curved pieces of glass that are inside. Have the class identify the kinds of lenses they find. (They should see single and double convex lenses.)

After the pupils have acquired these basic understandings about lenses, use the names (*convex and concave*) when referring to them and encourage your pupils to also use this new vocabulary.

Review Chap. 28, Inquiry 3. Ask those children who can to bring curved mirrors from home. Many families have small magnifying mirrors. Also, try to find a large curved polished reflector, such as the ones frequently mounted behind wall lamps and candle sconces. If you can find one that is silvered on both the front and back side, you will have an excellent example of both kinds of curved reflectors. Some polished shallow metal bowls also can be used to show what curved reflectors do to the size of the image they produce. Shiny spoons are also useful.

Allow the pupils to experiment with curved reflectors, such as mirrors, bowls, and spoons, and so on. Tell them to hold the objects close to the reflector. (Images of objects held at a distance from an inward curving reflector will be inverted. See Inquiry 4 in Chap. 32 for the reason.) Ask them to discover which kind of curved surface reflects an apparently enlarged image and which reflects an image that is apparently smaller than the object it reflects. (The image produced in an *inward curving reflector* seems to be larger than the object. The image produced in an *outward curving reflector* seems to be smaller than the object.)

Ask the pupils if they know the correct name for an inward curving reflector. (It is a *concave* reflector because it curves inward just as a concave lens does.) What would an outward curving reflector be called? (A *convex* reflector because it curves outward like a convex lens does.)

Encourage the pupils to state in their own words the following learnings about curved reflectors and to compare their ability to produce an image either larger or smaller than the object with the ability of lenses to make objects seem larger or smaller.

1. A *concave reflector* produces a *magnified image* of an object *held close to it.*
2. A *convex reflector* produces a *miniature image* of an object.
3. A convex *lens* and a *concave reflector* make objects or images of them seem *larger.*
4. A concave *lens* and a *convex reflector* make objects or images of them *seem smaller.*
5. *Lenses and curved reflectors are used to magnify or diminish the apparent size of objects.*

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. *Convex lenses* make the size of *an object seem larger.* Convex lenses bulge outward. *Concave lenses* make the size of an *object seem smaller.* Concave lenses curve inward. Lenses can make the size or an object appear to change.

A *concave reflector* produces an *enlarged image of an object held close to it.* A concave mirror curves inward. A convex reflector produces a *miniature image* of an object. A convex reflector curves outward.

Lenses and curved reflectors are used to magnify or diminish the apparent size of an object.

Chapter Thirty-Two

Mirrors and Reflection

INQUIRIES

1. How is the image in a plane mirror like the object it reflects? How is it different?

2. How is light from a plane mirror reflected? How can the position of an image in a plane mirror be predicted? Why are images in plane mirrors reversed?

3. What kind of images do convex reflectors form? How are convex reflectors used? How do convex reflectors reflect light?

4. What kind of images do concave reflectors form? How do concave reflectors reflect light? How are concave reflectors used?

1. How is the image in a plane mirror like the object it reflects? How is it different?

Review Chap. 28, Inquiries 3 and 4 for experiences and learnings about the reflection of light from the object to the mirror and from the mirror to the person who sees the mirror image.

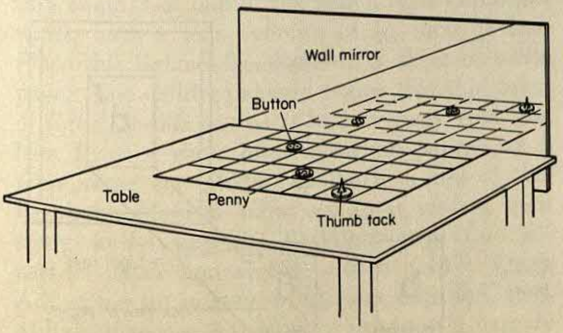
Borrow a wall mirror. Discuss with the children the difference between its surface and the surface of convex and concave mirrors. See Chap. 31, Inquiry 1. This wall mirror is called a *plane* mirror because its surface is *flat*. Have the meaning of the word *plane* checked in a dictionary.

Hang the wall mirror so that its lower edge is a little below table level. Place a table close to the wall in front of the mirror. Select such objects as a candle, a glass tumbler, a small vase, and a ball. Avoid objects that have printing on them. Refer to each of these things as an *object* and to the reflection of each of these things as the *image*. Place the objects on the table in front of the mirror. Move the objects away from and toward the mirror and observe what happens to the size of each image. (The image appears to be smaller when the object is farther from the mirror and larger when the object is nearer.)

Rule a piece of paper in inch squares. Place this squared paper on the table so that one edge touches the mirror. (See Fig. 32.1.) In the center row of squares, place a penny in the fourth square back from the mirror. In the mirror, where is the image of the penny? (It is in the fourth square. It appears to be four squares *behind* the mirror.) Place buttons, thumb tacks, and so on, in other squares. Observe their position in the image. (The image appears to be as far behind the mirror as the object is in front of the mirror. See Fig. 32.1.)

Some pupils may wish to do the experiment with candles for the class. The experiment will help the children find the *relationship between the distance of the object in front of the mirror and the distance that the image appears to be behind the mirror*. They will need a matched pair of candles that are 10 inches tall, a flat or plane mirror that is about 6 by 8 inches in size, and a ruler. Arrange the mirror so that it stands securely in a vertical position in the center of a table. Put both candles in holders. Light one candle. Stand the unlighted candle in front of the mirror so that *its top does not show in the mirror*. Place the lighted candle in back of the mirror. Observe the position of (1) the unlighted candle in front of the mirror and the image of the lower part of this candle in the mirror; and (2) the lighted part of the candle in back of the mirror (see Fig. 32.2, Step A). Move the lighted candle until its top coincides with the image of the lower part of the unlighted candle (see Fig. 32-2, Step B). Measure the distance from the front of the mirror to the unlighted candle and the distance from the back of the mirror to the lighted candle. (The distances will be equal.) The mirror-image of the lower part of the unlighted candle appears to be as far behind the mirror's surface as the unlighted candle is in front of it.

Fig. 32.1 The images of the objects seem to be as far behind the mirror as the objects are in front of it.



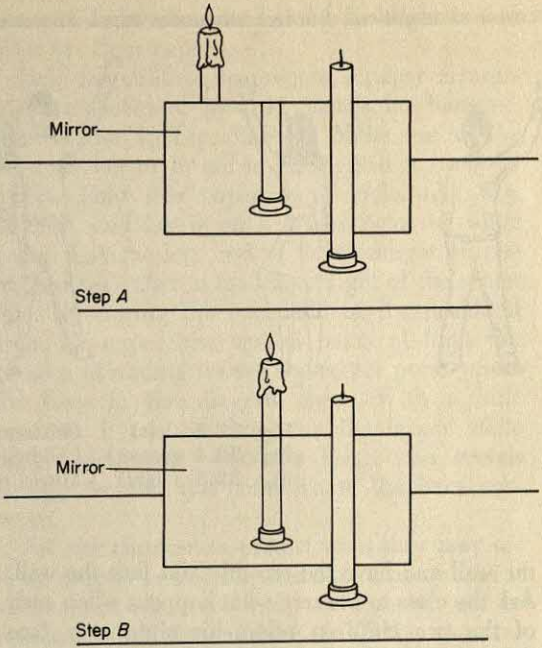
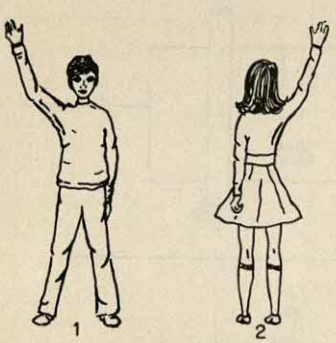
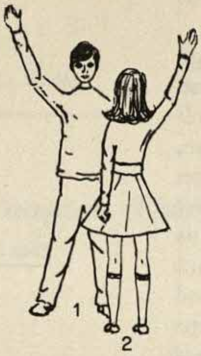


Fig. 32.2 How far behind the mirror does the reflection of the unlighted candle seem to be?

Arrange your class so that they are facing a wall on which a mirror has been placed. Stand two children side by side at one side of the mirror. Have one child stand with his back to





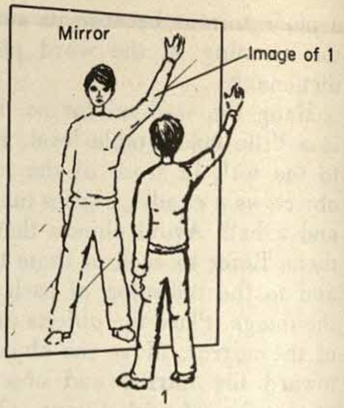


Fig. 32.3 (left) Children raise right hands.
Fig. 32.4 (center) Children raise right hands.
Fig. 32.5 (right) Mirror reversal of child's raised right hand.

the wall and have the second child face the wall. Ask the class to observe what happens when each of the two children raises his right arm (see Fig. 32.3). Ask the tallest child in the class to stand with his back to the wall, and the shortest pupil to stand facing him. Tell them to raise their right arms. Observe what happens (see Fig. 32.4). Ask another child to stand facing the mirror and to raise his right arm. Let the *class* decide which arm the child's image seems to raise. (The left arm.) Invite all the children to take turns facing their images in the mirror so that they can see *the reversals of their images from right to left* (see Fig. 32.5).

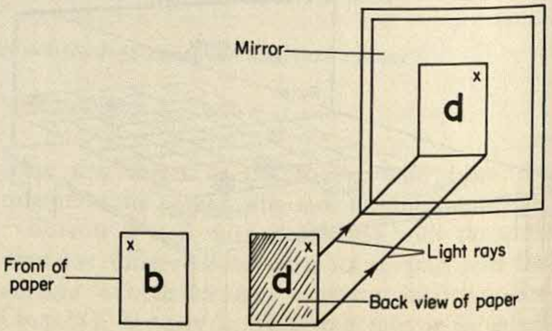
Bring some lipstick and dark eye shadow to school. Choose a child who is willing to have these cosmetics applied on his face and to be a part of this experiment. Use the eye shadow to give the child a "black eye." Color the cheek on the opposite side of his face a bright red. Ask the class to study the child's face and to observe silently which eye is black and which cheek is red. Give paper and crayons to the child who has been "made up." Ask him to go to the mirror and draw the image of his face *as he sees it in the mirror.* Tell the class to use their crayons and paper and draw the child's face *as they saw it.* Pin the child's portrait of his mirror-image and one of the children's portraits of him on the bulletin board. Compare the two portraits.

Discuss the fact that you *never really see yourself in a mirror as others see you* because your image is reversed.

Ask several of the children to set up the experiment shown in Fig. 32.6. If they print the letter *b* with a black ink marker on thin paper, the class will be able to see the letter reversed to the letter *d* through the paper. Remind the pupils setting up the experiment to place the letter *x* in the *upper left-hand corner* of the paper. When this letter is viewed from the back, it will still be the letter *x*. How then is it reversed when seen through the paper? (It will appear to be in the *upper right-hand corner.*)

Now have the children hold the paper with the letter *b* and the letter *x* facing the mirror and observe the image. What reversals are in the image? (The *b* is reversed to a *d*. The *x* is

Fig. 32.6 The image in a plane mirror is reversed. The object "b" written on paper appears in the image as letter "d." The letter "x" written in the upper left-hand corner of the paper appears in upper right-hand corner in the mirror image.



reversed from the top left corner to the top right corner.)

The children may want to print different letters on paper and observe the image reversals that occur. Have them print their name and observe the image reversal of it. They will also enjoy seeing their handwriting reversed in the mirror image.

Show the children how to do "mirror writing." In "mirror writing," you reverse each letter, reverse the order of the letters, and reverse the words (see Fig. 32.7). They can check the accuracy of their "mirror writing" by holding it in front of a mirror. If their printing is correctly reversed on the paper, the mirror image will reverse the letters, the order of the letters, and the order of the words back to normal.

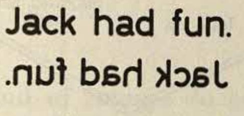

Jack had fun.

Fig. 32.7 Reverse these sentences in a plane mirror.

2. How is light from a plane mirror reflected? How can the position of an image in a plane mirror be predicted? Why are images in plane mirrors reversed?

Light when it strikes a shiny surface, called a reflector, is bent back or reflected. (See Chap. 28, Inquiries 3 and 4.)

In order to see how light is reflected from a plane mirror it is necessary to have a small, thin beam of light. Here is one way to get such a thin beam. Get one of the pencil type flashlights which have a lens opening of 1/4 inch or less. Place this lighted flashlight on a sheet of white paper. The children should notice that this beam of *light spreads out as it travels* away from the lens. From a sheet of new carbon paper, cut a piece large enough to cap the lens end of this flashlight. Make a *short slit* in it with a very sharp knife. Cap the flashlight with this slit carbon paper and secure with a rubber band. Adjust the slit in front of the lens until the beam of light that passes through it produces a narrow beam of light when the lighted flashlight is laid close to white paper.

Help the children to prepare a paper measuring instrument at least 12 inches in diameter, like the one in Fig. 32.8(a). Make one of the lines blacker or in red to distinguish it from the others. Fold this paper so it looks like Fig. 32.8(b) and lay it on a larger piece of white paper. Lay the lens end of the flashlight on one of the lines either to the left or right of the center line. By raising the back end of the flashlight from the paper, the narrow beam of light can be seen extending toward the center point where the lines in the diagram meet. With a little practice, it can be shown on the larger white paper background that the beam also travels straight beyond the point where the lines converge.

Ask the children to predict what they may see if the narrow beam of light strikes a plane mirror at the point where the lines converge. (It will be reflected.) *Let the children see if they can use these two tools and a plane mirror to discover where the reflected beam of light always travels.* [Lay the folded paper instrument on a table so that it touches the surface of the plane mirror as shown in Fig. 32.8(c).] A narrow beam of light along any line to the left or right of the center line will strike the mirror where the lines converge. The beam will be reflected from the mirror at this point and the reflected beam will *show on the paper*. It will help the children to concentrate on the *reflected beam on the paper*, if a paper shield is taped to the surface of the mirror to conceal the image. Expose only that small area of the mirror where the light strikes it. The children will discover that a beam shining along any line to the left or right of the center line will be reflected by the mirror on the corresponding line that is to the right or left of the center line.

Explain that the space between two straight lines that meet is called an *angle* and that *angles are measured in degrees*. Tell them that the center line which is darker or a different color is the 0-degree line and that the line on which the folded paper touches the mirror is the 90-degree line. Put these numbers on the paper instrument they are using to observe the angles at which light approaches the mirror and is reflected from it. [See Fig. 32.8(c).] Help them to see that the first lines to the right and left of the 0-degree

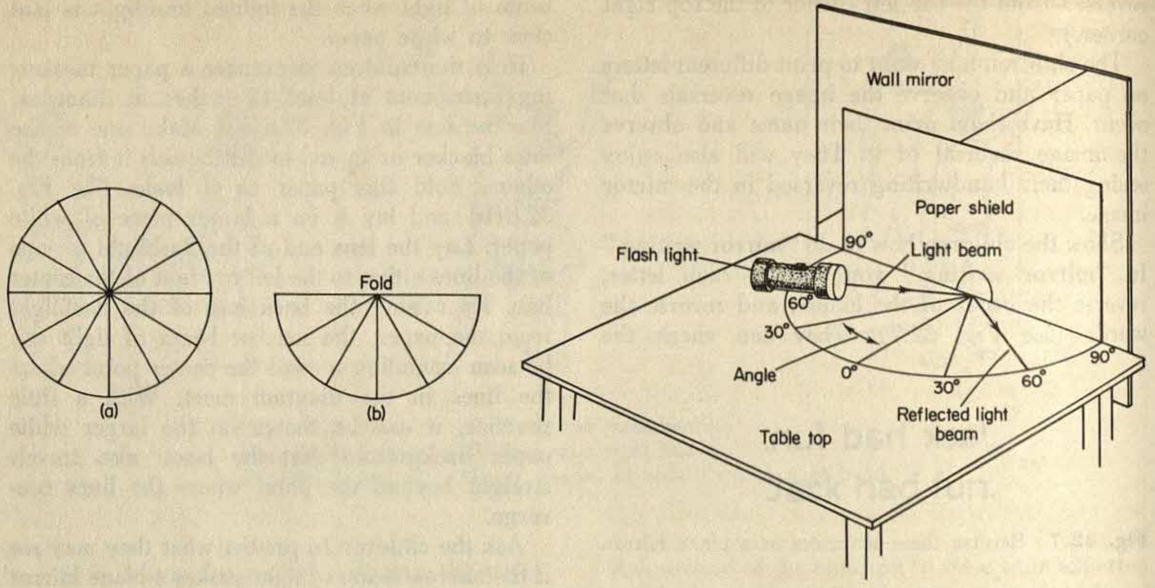


Fig. 32.8 Preparing and using an instrument for measuring the angle of reflection.

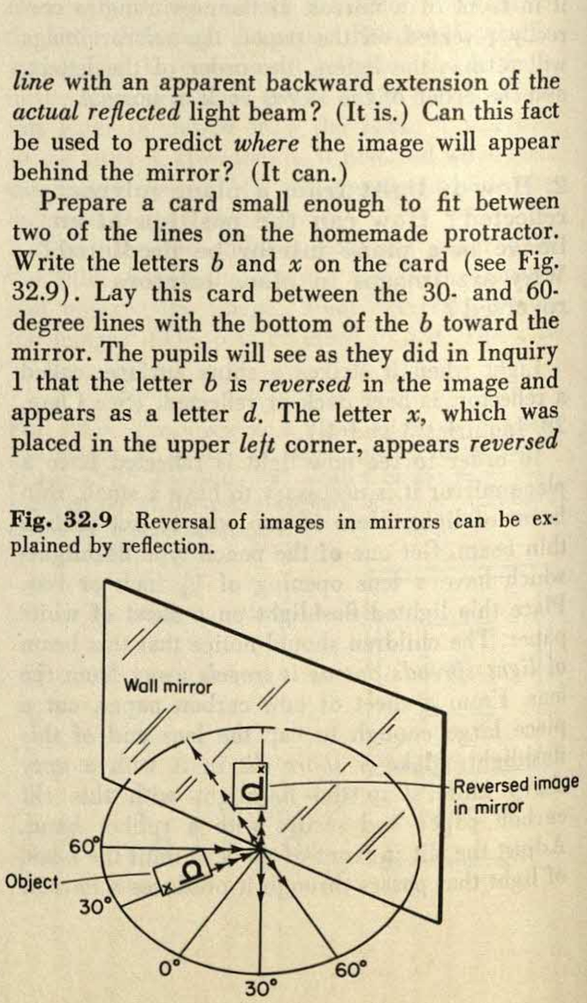
line are both 30 degrees and the second lines to the right or left of the 0-degree line should both be labeled 60 degrees. Repeat the experience with the flashlight, the plane mirror, and the paper measuring tool and help the pupils to form the understanding that *light is reflected by a plane mirror at the same angle at which it strikes the mirror* and that this angle can be measured in degrees.

Some of the students may have protractors in their pencil boxes. Show them some real protractors. Help them to see that their measuring device is only a homemade protractor. Some of the students should be encouraged to repeat the experiment with a real protractor.

Have the pupils repeat the previous experience with the paper shield removed from the mirror. This time, have them observe the position of the *image of the flashlight* in the mirror and the *image of the light beam leaving the flashlight.* Help them to see that these *two images appear to be behind the mirror.* They should also see that the *image* of the light beam leaving the flashlight appears to be a backward extension behind the mirror of the light beam reflected on the homemade protractor. Have the pupils shine the lighted flashlight at the mirror from different angles. Is the *image* of the light beam always *in line* with an apparent backward extension of the *actual reflected* light beam? (It is.) Can this fact be used to predict *where* the image will appear behind the mirror? (It can.)

Prepare a card small enough to fit between two of the lines on the homemade protractor. Write the letters *b* and *x* on the card (see Fig. 32.9). Lay this card between the 30- and 60-degree lines with the bottom of the *b* toward the mirror. The pupils will see as they did in Inquiry 1 that the letter *b* is *reversed* in the image and appears as a letter *d*. The letter *x*, which was placed in the upper *left* corner, appears *reversed*

Fig. 32.9 Reversal of images in mirrors can be explained by reflection.



to the upper *right* corner in the image. Ask the pupils to explain this reversal. (See Fig. 32.9.) (Light traveling from the stem of the letter *b* and from the letter *x* follow the 30-degree line at the left of 0 degrees and is reflected by the mirror on the 30-degree line at the right of zero. Follow this reflected light backward and see the stem of the *b* and the *x* in the image. Light traveling from the outer curve of the letter *b* follows close to the 60-degree line at the left of zero and is reflected by the mirror near the 60-degree line at the right of zero. Follow this reflected light backward and see how the curved part in the image attaches to the left side of the stem to form the letter *d*.)

3. What kind of images do convex reflectors form? How are convex reflectors used? How do convex reflectors reflect light?

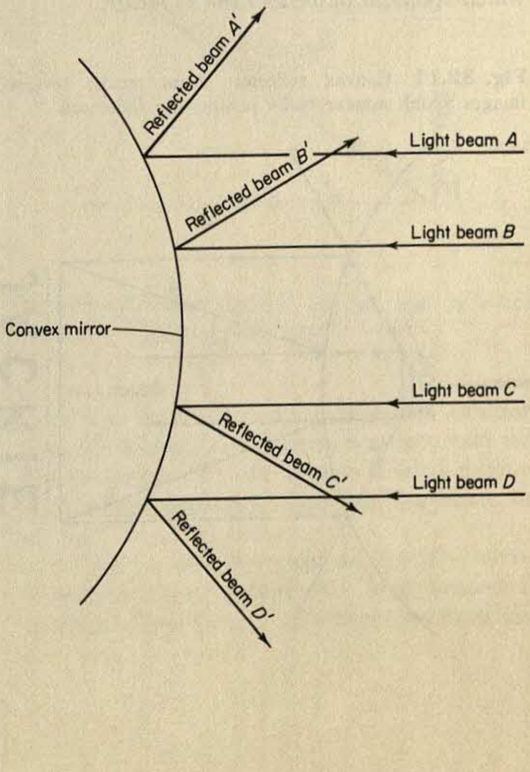
In Chap. 31, Inquiry 1, the pupils saw that a convex reflector produced a *miniature image* of an object. They know from Inquiry 2 of this chapter that in a plane reflector (1) the image is reversed and (2) the image seems to be behind the reflector. *Are the miniature images in convex reflectors reversed and do they seem to form behind the reflector?* The *backs* of large, shiny spoons make useful convex reflectors. By using them and repeating some of the plane mirror experiments, each pupil can see for himself that convex reflectors (1) produce miniature images, (2) form images that are reversed, and (3) produce images that seem to form behind the reflector. With these spoons, repeat the experiences shown in Figs. 32.1, 32.5, 32.6, and 32.7.

Encourage each pupil to use the convex side of a shiny spoon to observe the scene behind him. Have him name the objects whose images he can see in the reflector. (He should be able to name *many*.) Repeat with a small plane mirror that is approximately the same size as the spoon. A mirror from a woman's purse could be used. Hold both the plane mirror and the convex reflector the same distance in front of the eyes. In which of the two reflectors can more images be seen? (In the convex reflector.) In which can a larger area be seen? (In the convex reflector.)

Have each pupil look at his own image first in the back of a spoon and then in a small plane mirror. In front of each reflector do these suggested things. Touch the nose with the left hand and then stretch the hand and arm away from the head until the image of the hand can no longer be seen in the back of the spoon. Repeat with the right hand and arm. What difference does this simple measuring device show? (In the convex reflector the image of the hand and arm can be seen even when the arm is fully extended. In the plane mirror, they can be seen only when partially extended.) Which reflector reflects a larger area? (The convex reflector.)

Have the children explain why some trucks are equipped with convex reflectors. (They give the drivers a view of a wider area than a plane mirror does.) Many mail trucks and school buses are equipped with convex reflectors. Also, many stores use convex reflectors to help reduce the amount of shoplifting. Take the children where they can see one of these convex reflectors. Let them see and feel the convex surface of the reflector and observe the wide area that it reflects. (Mail trucks have the convex mirror mounted to reflect the area immediately ahead of the front bumper. Store convex reflectors are mounted

Fig. 32.10 Reflected light from parallel beams is spread out or diverged by a convex reflector.

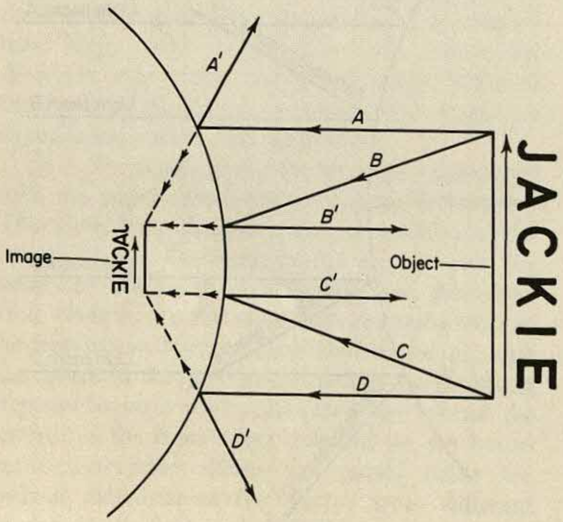


where a very large area of the store and the shoppers in it can be watched.)

The same pen flashlights prepared for use in the experiment shown in Fig. 32.8(c) can be used to shine narrow, parallel beams of light at a large convex reflector. The shiny bottoms of metal mixing bowls can be used. If a white paper base is used as in Fig. 32.8(c) and the experiment is performed in a darkened room, the reflected beams will be visible on the paper. This paper does not need to be in the form of a measuring device. The reflected beams will be spread out or *diverged* (see Fig. 32.10).

Ask each pupil to cut a small piece of white paper that is approximately 2 inches by ½ inch. On it with a pointed black crayon each child can print his name, underline it, and put an arrow point on one end of the line (see Fig. 32.11). Hold this paper so an image of it can be seen in the convex back of a large shiny spoon. How can the image be described? (It is small, reversed, and seems to be behind the reflector.) See Fig. 32.11 for a diagram of this experience. In the diagram see (1) the beams of light drawn from the object to the reflector (beams *A*, *B*, *C*, and *D*) and (2) the reflected beams A^1, B^1, C^1, and D^1. Finally follow the backward extensions of beams A^1, B^1, C^1, *and* D^1 (which are shown as broken arrows) to the *small, reversed image,* which *seems to be behind the reflector.*

Fig. 32.11 Convex reflectors form small, reversed images which appear to be behind the reflectors.



4. What kind of images do concave reflectors form? How do concave reflectors reflect light? How are concave reflectors used?

Each pupil has a small piece of white paper on which he printed his name, underlined it, and put a point on one end of the line. Each should now hold this marked paper *very close* (almost touching) and facing the *bowl* of the large shiny spoon. The bowl is a concave reflector. What kind of image forms? (The image is *magnified, reversed,* and *seems to form behind the reflector.*) How is this image different from the one in a convex reflector? (The concave reflector formed a *magnified* image; the convex reflector, a *miniature* image.) Repeat the experiment. Continue it by slowly moving the paper and spoon farther apart. What can be seen? (When the object and reflector are first moved apart, the magnified, reversed image will disappear. When the object and reflector *are moved still farther apart, a very tiny image of the paper* will reappear. The writing on it will be too small to see.) What else can be seen besides the tiny image of the paper? (The child will be able to see the image of his own head and hand as well as the tiny image of the paper.) What is interesting about the image of the head and hand? (The image of the head is upside down or inverted. By spreading and wiggling the fingers, the image will show that the hand also is inverted. The image of the hand is *not reversed* from left to right or from right to left.) If a larger concave reflector is used, it is possible to see also that the images now *do not seem to form behind the reflector; rather, they seem to form in front of it.*

How is this image different from the one when the object was held very close to the concave reflector? How is it the same? See Table 32.1 for answers.

It may be helpful at this time to introduce the concept of *virtual and real* images. When an image seems to form behind a reflector, it is called a *virtual image.* The word virtual is a good word to describe this kind of image, because an image cannot *really* form behind an opaque reflector, but the image does seem *virtually* (in effect) to be there. *Real* images are always inverted and they form in front of the reflector.

Table 32.1

IMAGES FORMED IN CONCAVE REFLECTORS

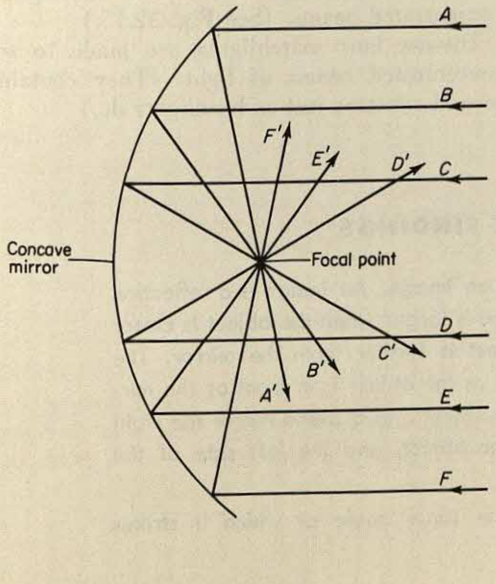
When Object Is Held *Very Close*	When Object Is Held *Far Away*
Magnified	Miniature
Reversed	Not reversed
Upright	Inverted
Seems to form behind reflector	Forms in front of reflector
Virtual image	Real image

The same pen flashlights which were prepared for use in the experiment shown in Fig. 32.8(c) can be used again to shine narrow parallel beams of light at a large concave reflector. The inside of a shiny, metal mixing bowl can be used. If a white paper base is used as in Fig. 32.8(c) and the experiment performed in a darkened room, the reflected beams will be visible on the paper. The base can be a single sheet of white paper; it does not need to be a measuring device of any kind. The beams will be reflected by the concave reflector in such a way that they collect or *converge* (see Fig. 32.12). See Figs. 32.13 and 32.14, which show how both the *virtual* and *real* images are formed on concave reflectors.

Have the children try to find information similar to the following about the use of concave reflectors. Because concave reflectors can form magnified images of objects that are held near their surfaces, they are used as "beauty mirrors" for plucking eyebrows, removing blackheads, and so on.

In some countries people use concave mirrors to obtain from sunlight the heat needed for cooking. Some day, in countries that have clear

Fig. 32.12 A concave reflector reflects and converges light beams.



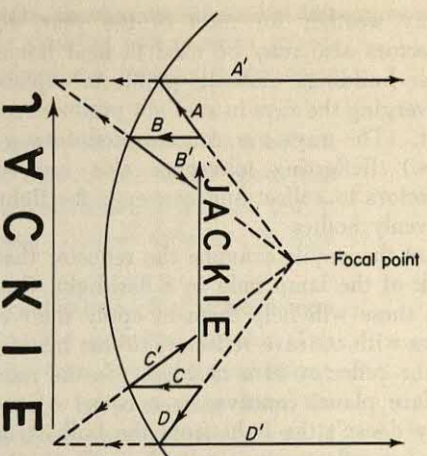


Fig. 32.13 When objects are held very close to a concave reflector, a magnified, virtual image is formed which appears to be behind the reflector.

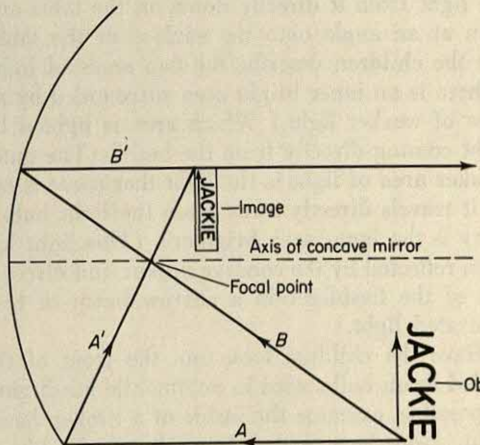


Fig. 32.14 When objects are far from a concave reflector, an inverted real image is formed.

sunny weather for most of the year, concave reflectors also may be used to heat homes and other buildings. Ask the pupils to explain why converging the rays in sunlight produces so much heat. (The rays are concentrated into a small area.) Reflecting telescopes also use concave reflectors to collect and converge the light from heavenly bodies.

Let the pupils examine the reflector that is in back of the lamp bulb in a flashlight. Questions like these will help them to apply their experiences with concave reflectors to this investigation of the reflector in a flashlight. Is the reflector's surface plane, concave, or convex? (Concave.) Why doesn't the light from the bulb strike this concave reflector in parallel beams? (Light from a bulb is emitted in all directions.) Where is that portion of the light that strikes the surface of the reflector reflected? (It is reflected out of the flashlight.)

Hold the flashlight close to a table and shine the light from it directly down on the table and then at an angle onto the surface of the table. Let the children describe the two areas of light. (There is an inner bright area surrounded by an area of weaker light.) Which area is lighted by light coming directly from the bulb? (The outer weaker area of light is the light that spreads out as it travels directly away from the light bulb.) Why is the inner area brighter? (This light has been reflected by the concave mirror and directed out of the flashlight in a narrow beam of concentrated light.)

Have the children look into the front of the sealed beam bulbs used in automobile headlights. If possible, examine the inside of a broken headlight. How is a sealed beam headlight like a flashlight? (It has a concave reflector to direct the light out in a narrow beam of concentrated light.) How is it different? (The light source is a wire filament and not a light bulb. There is another small concave reflector between the light source and the lens of the headlight.) Ask the children to guess what this second reflector does. (It collects the light that would normally travel out of the headlight and reflects it to the large concave reflector. The large concave reflector reflects this light out of the headlight in concentrated beams. (See Fig. 32.15.)

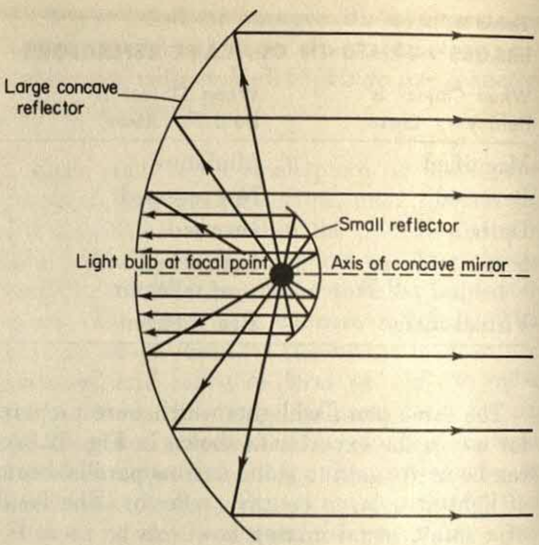


Fig. 32.15 The large concave reflector reflects some of the beams from a light source as parallel beams of light. A small concave reflector is used in headlights and searchlights to direct the rest of the beams from the light source back to the large concave reflector.

Discuss how searchlights are made to send concentrated beams of light. (They contain a second reflector just as headlights do.)

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. The picture we see in a mirror is called an image. An image is a reflection of the objects in front of the mirror. The image is larger when the object is closer to a plane mirror and smaller when the object is farther from the mirror. The image appears to be as far behind the mirror as the object is in front of the mirror. Plane mirror images are reversals of the objects. In a plane mirror the right side of the image is really the left side of the object, and the left side of the image, the right side of the object.

2. Light is reflected by a plane mirror at the same angle at which it strikes the mirror. The image is reversed. The image seems to occur as far behind the mirror as the object is in front of the mirror. The position and reversal of an image can be predicted. The image always forms where the *reflected light seems to extend behind the mirror.*

3. Convex reflectors produce small, reversed images which seem to form behind the reflector. Convex reflectors reflect the images of objects in a wider area than can plane mirrors. Convex reflectors are used in places where it is important to obtain a mirror view of objects located in a wide area. Convex reflectors diverge (spread out) parallel beams of light.

4. Concave reflectors form both a virtual and a real image. The virtual image in produced whan the object is held very close to the concave reflector. This image is *magnified, reversed, upright,* and *seems to form behind the reflector.*

The *real* image is formed when the object is held at a distance from the concave reflector. The image is *miniature, not reversed, inverted,* and *forms in front of the reflector.*

Concave reflectors concentrate light. They are used in flashlights, headlights, searchlights, and in reflecting telescopes.

Chapter Thirty-Three

Refraction and Lenses

INQUIRIES

1. Under what conditions do objects appear to be bent when they are underwater? When do they look magnified? When do they not appear bent and magnified?

2. What happens to a beam of light when it enters and leaves water? In what directions are light beams refracted when they enter and when they leave water?

3. What happens to a beam of light when it enters and leaves the plane surface of thick plate glass? In what directions are light beams refracted when they enter and when they leave plate glass?

4. What other transparent media refract a slanting beam of light?

5. How do transparent materials that refract light differ? How do transparent materials of different densities affect the speed of light?

6. Which way is a slanting beam of light refracted when it enters a more dense transparent medium? A less dense medium? When will the speed of light be decreased? When will the speed of light be increased?

7. What kinds of illusions are caused by refraction?

8. What causes convex lenses to converge light? What causes concave lenses to diverge light?

9. What kinds of images can be seen with convex lenses? What causes these images to form?

10. What kind of image can be seen with a concave lens? What causes this image to form?

11. How is light refracted when it enters and leaves a prism? How are the spectral colors separated from white light by a prism?

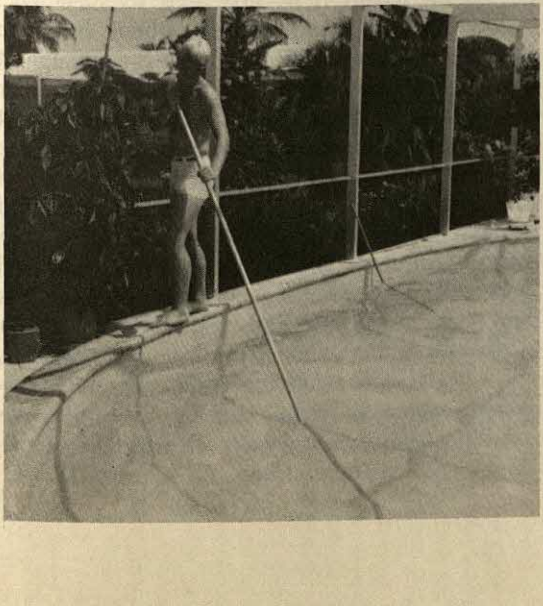
12. What other things, besides a triangular prism, can be used to separate the spectral colors in white light?

1. Under what conditions do objects appear to be bent when they are underwater? When do they look magnified? When do they not appear bent and magnified?

Look at Fig. 33.1 and speculate why the brush handle appears bent.

Partially fill a glass tumbler with water. Put a pencil in the *center* of the tumbler and lean the top against the rim. Look at the pencil through the *side* of the tumbler. (The pencil will appear to be bent at the water's surface. The part of the pencil that is underwater will also appear to be magnified. See Chap. 31, Inquiry 1.) Stand up and look straight down into the tumbler of water. (From this position, the pencil will appear to be normal in size and shape.) Experiment with other *partially* submerged objects, such as a ruler, a small plastic doll, and waterproof toys. Observe how they appear. (The results will be the same.)

Fig. 33.1 Refraction causes the pole to appear to be bent at the surface of the water.



Completely submerge small objects, such as coins, paper clips, and thumbtacks. Look at these objects from the side and from the top. Compare the appearance of objects that are partially and completely submerged. (There is only one difference. When the submerged object is viewed from the side, it is *not bent.*) Ask the children to give their own opinions about why this difference occurs. From experiences in earlier chapters, the pupils should be able to make statements and guesses similar to these: (1) We see objects by reflected light. (Chap. 28, Inquiry 5.) (2) When objects *are not in water,* we see them by reflected light that travels through air. (3) When objects *are in water,* we see them by reflected light, which travels through both water and air. (4) Maybe water acts like a lens. (Chap. 31, Inquiry 1.)

2. What happens to a beam of light when it enters and leaves water? In what directions are light beams refracted when they enter and when they leave water?

Check the children's guesses made in the previous inquiry by having them do this experiment.

Put two quarts of water into a rectangular one-gallon aquarium; if larger, add enough water to partially fill it. Place a mirror in the bottom of the aquarium. (See Fig. 33.2.) Add a few drops of milk to the water. Darken the room. Direct a narrow beam of light from a flashlight (see Chap. 32, Inquiry 2) at an angle onto the mirror. Clap two chalkboard erasers together to release enough dust to make the beam of light visible in the air above the water.

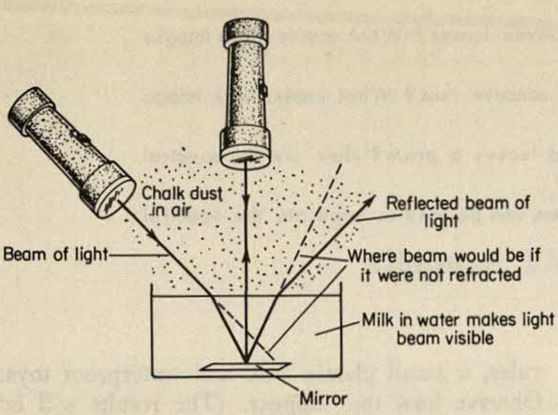

Chalk dust in air
Reflected beam of light
Beam of light
Where beam would be if it were not refracted
Milk in water makes light beam visible
Mirror

Fig. 33.2 A slanting beam of light is refracted as it enters water and again as it leaves water. A perpendicular beam is not refracted.

The milky water will reveal the path of the beam underwater. Call the children's attention to the bending of the light beam (1) as it *enters* and (2) as it *leaves* the water. During the discussion of the experiment, substitute the word *refracted* for bent. Also, have the pupils define the words *refract* and *perpendicular*.

In the last experiment, the class observed the refraction of a slanting beam (1) as it left the air and entered the water and (2) as it left the water and entered the air. Set up the same experiment again. Place two rulers into the tank of water and hold them in a perpendicular position. Place one ruler where the light beam strikes the water and the other where the reflected beam leaves the water. Observe the directions in which the beam from the *light source* and the *reflected beam* are refracted. Make certain that the children observe that the light is refracted *toward the ruler* (the perpendicular) when it enters the water and *away from the ruler* (the perpendicular) when it leaves the water. Ask several of the pupils to look in encyclopedias under the word refraction for the term that is used to designate the *perpendicular*, as represented by the ruler in this experiment. (A line drawn *perpendicular* to the surface of a transparent medium into which a slanting light beam is entering is called *a normal.* Hold the flashlight in a perpendicular position (at right angles) to the surface of the water and observe what happens. (The beam will not be bent as it enters or as it leaves the water.)

3. What happens to a beam of light when it enters and leaves the plane surface of thick plate glass? In what directions are light beams refracted when they enter and when they leave plate glass?

Encourage the pupils to test the refraction of a slanting beam of light as it *enters and leaves* a thick layer of plate glass. (The light beam is refracted *toward the normal* when it enters the glass and *away from the normal* when it leaves the glass.)

4. What other transparent media refract a slanting beam of light?

Have the pupils repeat the procedures in Inquiries 1, 2, and 3 with such transparent media as honey, syrup, alcohol, antifreeze, lighter fluid, dry cleaning fluid, salt water, ammonia, thick plastic, and so on. If they observe any refraction in these media, ask them to (1) *observe the direction* of refraction that occurs as the light beam enters and leaves the medium, and (2) *compare the amount* of refraction in the new material with the amount in water or glass.

5. How do transparent materials that refract light differ? How do transparent materials of different densities affect the speed of light?

Explore the student's ideas about how the liquids they have used differ. They may suggest that some, like honey and syrup, seem thicker and do not pour as easily as others. Explain that the term is *dense* and that a *dense substance weighs more than an equal volume of a less dense substance.* Have the class keep this fact in mind while they decide which one of each of these pairs of substances is more dense: (1) *lead* and cork; (2) cotton batting and a *stone;* (3) cork and *water;* (4) air and (liquid) *water;* (5) *glass* and water; and (6) air and *glass.* (Air, glass, water, and many other materials are transparent media to visible light.) Each of these media has a *different density*. Provide the experiences on density in Chap. 6, Inquiry 12.

The speed of light differs as it travels through transparent materials that have *different densities.* Light travels about 186,000 miles per second in a vacuum. Because the speed of light is *only slightly changed in air,* this figure (186,000) is also used for the speed of light in air. However, when light travels from air into more dense transparent substances, such as water and glass, its speed changes. Let the children deduce whether light would travel faster or slower in a medium that is more dense than air. (Slower. The speed of light in water is almost 140,000 miles per second, and in ordinary glass, 124,000 miles per second.) In a medium that is less dense than water? (Faster.)

6. Which way is a slanting beam of light refracted when it enters a more dense transparent medium? A less dense medium? When will the speed of light be decreased? When will the speed of light be increased?

Help the children make a large diagram which shows what happened to the light beam in the experiment with the two rulers. Have the pupils draw a second large diagram to show what happened to the light beam in the experiment with the thick piece of plate glass.

Use these diagrams to help the pupils find the relationship between the density of a transparent medium and the direction in which a slanting beam of light is refracted. (The slanting beam of light will be refracted toward the normal when it enters a more dense transparent *medium* and away from the normal when it enters a less dense, transparent *medium.*) After the class has studied the diagrams, ask them to answer the following questions. (1) Will a slanting beam of light be refracted *away from* or *toward* the *normal* when it enters the surface of a *more* dense transparent medium. (Toward the normal.) (2) If a slanting beam of light enters a *less* dense transparent medium, in which direction will it be refracted? (Away from the normal.) Check the children's answers to the questions. Have several pupils who answered the questions correctly use the two large diagrams to explain to the class why they think their answers are correct. During the discussion of the diagrams, ask the class whether they think there will be a change in the speed of a light beam where it enters a transparent medium of different density. (The speed will change, even though it may not be refracted.)

7. What kinds of illusions are caused by refraction?

Use Fig. 33.1 to explain why the bent brush handle is only an illusion caused by refraction.

Have the students make diagrams to explain why the pencil in the experience in Inquiry 1 appears to be bent. (This is the same kind of illusion.)

Use the following experiment to find out whether the children can apply their experiences with the refraction of light to a new situation (see Fig. 33.3.). Place a coin in an opaque cup. Ask a child to stand where he can see the coin in the cup. Then have him move backward one step. The coin will disappear from his view. Have another child pour water very slowly into the cup and the coin will reappear. Why? (The reflected light from the coin was refracted.) Was the light from the coin refracted toward or away from the normal? (Away from the normal.) As a further check on the pupils' understanding, ask them to draw one or more diagrams similar to the ones in Fig. 33.3 and use them to explain why the coin reappeared.

Perhaps some of the children will have had the experience of diving to the bottom of a body of water to retrieve a lost article. If they have, let them relate their experiences. (The subject they were retrieving seemed to be *deeper and farther away* than they expected it would be.)

Fill a deep glass container with water. Drop a magnetic (attracted by a magnet) paper clip into the container and let the children "fish" for the clip. Use a ruler for the fish pole, string for the fishline, and a small magnet for the fish hook. Have the children take turns standing at one side of the container and try to catch the paper-clip fish. Ask them to explain why it is difficult to drop the magnet onto the clip *when they stand at one side.* (The light from the paper clip has been refracted, causing the clip to *seem to be where it is not.*) Let the pupils suggest a posi-

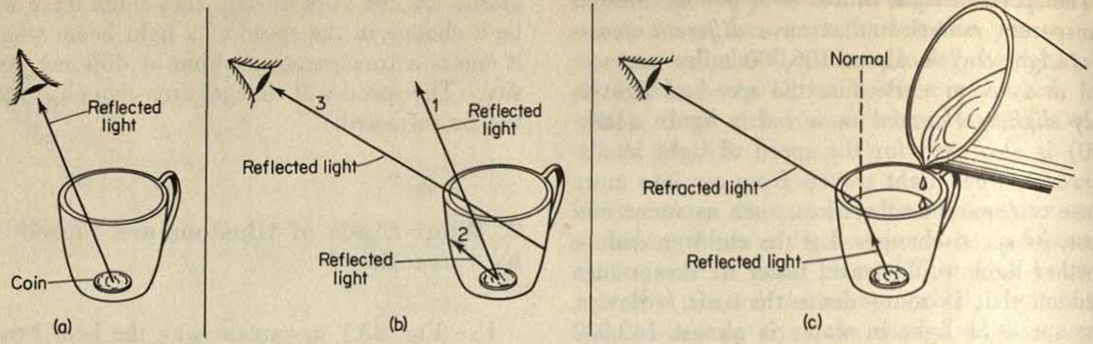


Fig. 33.3 (a) The child's eye sees the coin because the *reflected* light from the coin travels straight to his eye through the density of one medium—air. (b) When the child moves backward, his eye is out of range of beam 1 reflected from the coin. The side of the cup prevents reflected beam 2 from reaching his eye. He cannot see the coin because none of the light reflected from it can reach his eye. He can see the inside of the cup beyond the coin by reflected beam 3. (c) As water is poured into the cup, the coin reappears because the reflected light from the coin is *refracted away from the normal* as it leaves the more dense medium, water, and enters the less dense medium, air.

tion from which the clip can be seen by *light that is not refracted.* (Lean over the top of the container and look directly down at the clip. Light that either enters or leaves a medium at right angles, or perpendicularly, is not refracted.)

Find out whether the children have seen the pavement, in front of a car in which they were riding, appear to be wet when it really was dry. They may also have read stories about thirsty travelers in the desert who see pools of water where there are none. These illusions are called *mirages.* Ask the pupils to look for information about the cause for these mirages. (These mirages occur on days when the *sky is bright* and when the *ground or pavement is so very hot* that it causes a layer of air above it to be warmer and less dense than the air higher up. When, ahead of the observer, slanting bright sky light enters this warmer less dense layer of air from the cooler more dense layer above, it is *refracted or bent upward* to the observer's eyes before it reaches the ground. The observer really sees this bright *refracted* sky light. But, because he has learned to associate such bright light with light *reflected from the surface of water,* he makes the false conclusion that he is seeing bright light reflected from water. Also, because he cannot see where the bright sky light is refracted *above the ground,* he makes a second false conclusion that this bright light is reflected from water *on the ground ahead of him.*)

8. What causes convex lenses to converge light? What causes concave lenses to diverge light?

Test both single and double convex lenses. Shine narrow beams of light from two flashlights through each. Direct the two beams parallel to each other so that they pass through two places midway between the center and the edge of the lens. Chalk dust in the air will be helpful. [See Figs. 33.4(a) and 33.4(b).] Why are the beams *not parallel after* they pass through a convex lens? (A convex lens *converges* the two beams to a focal point.) Repeat the experiment with single and double *concave* lenses. Why are the two beams *not parallel after* they pass through a concave lens? (The concave lens *diverges* the light.) Find out whether the class can explain what caused the beams of light to change direction. (The beams were refracted by the lenses.)

Use the large paper model of the single convex

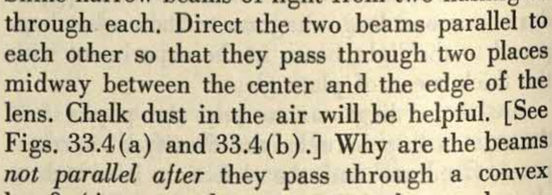


Fig. 33.4 (a) A single convex lens converges parallel beams of light. (b) A double convex lens converges parallel beams of light.

lens the children made during their investigation in Chap. 31. Attach this model to the chalkboard. Have the pupils draw two parallel beams to the plane surface of this lens [see Fig. 33.4(a)]. Observe that the beams are not refracted when they enter the plane surface of this lens. Why are they not refracted at this surface? (When light enters perpendicularly to the surface of a medium, it is not refracted.) Draw the two parallel beams so they show refraction at the point where they leave the lens. Also show how the two refracted beams *converge* at a point called the focal point.

Ask a group of children to make a bulletin board model which shows what happens when parallel light beams enter and leave a double convex lens. [See Fig. 33.4(b)]. What happens to the light that passes through a double convex lens? (The light is converged to a focal point.) Repeat the previous procedures for both single and double concave lenses. Also, have the pupils show that concave lenses *diverge* parallel beams of light.

9. What kinds of images can be seen with convex lenses? What causes these images to form?

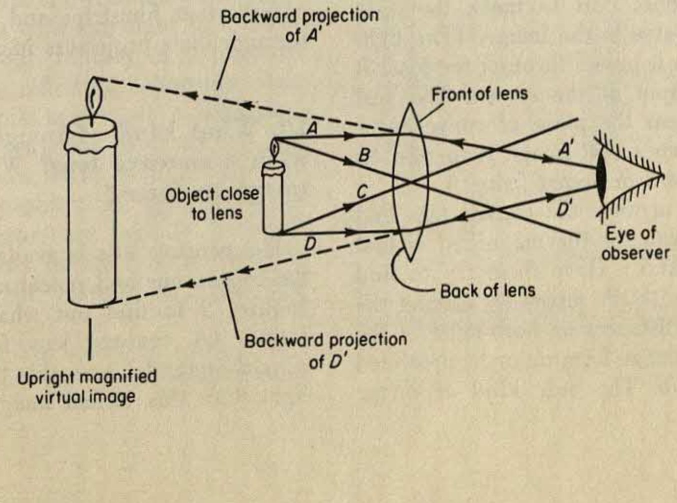
Divide the class into small groups. Give each group a magnifying glass (a convex lens) and a yardstick or a meter stick. Tell these groups to choose an object to observe through their magnifiers. Instruct them to observe the object from *different distances*. Ask them to find out whether *distance* causes any difference in the kind of image that they see. (When an object *close* to the magnifying lens is observed through it, the image will appear *upright, magnified,* and *seem to be behind the lens.* When an object *far* from the lens is observed through it, the image will appear *small, inverted,* and *seem to be in front of the lens.*)

Ask each group to record the distance between the lens and the object when they see either image. (They should discover that the distance is small when the upright magnified image forms and that the distance is large when the small inverted image forms. This distance varies with the magnification power of the lens, and for this reason, the different groups probably will find that their distances do not agree.)

Have the pupils recall the difference between the *real* and *virtual images* formed by a concave reflector. (See Chap. 32, Inquiry 4. Also see Figs. 33.5 and 33.6.) What is the name of the upright magnified image that is formed by the convex lens when the object is close to the lens? (It is a *virtual* image.) Which kind of image is the *small inverted image* formed by this convex lens when the object is far from the lens? (It is a *real* image.)

The experiment shown in Fig. 33.7 will help the children discover another difference between the upright, *virtual* image and the inverted, *real* image. A piece of glass, approximately four

Fig. 33.5 A convex lens forms a magnified, upright, virtual image which seems to be behind the lens. For this reason, convex lenses are used in magnifying glasses.


Backward projection of A'
Front of lens
A
B
A'
C
Object close to lens
D'
D
Eye of observer
Back of lens
Backward projection of D'
Upright magnified virtual image

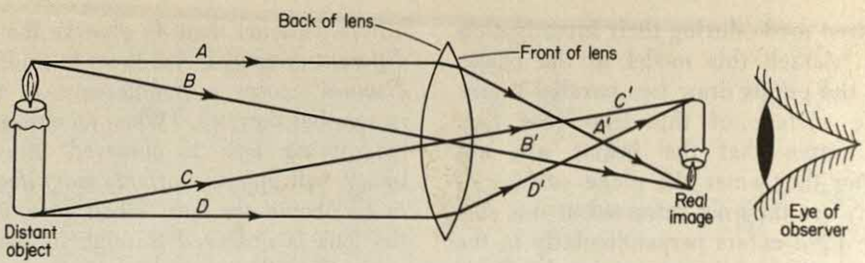


Fig. 33.6 A convex lens forms a small, inverted, real image in front of the lens.

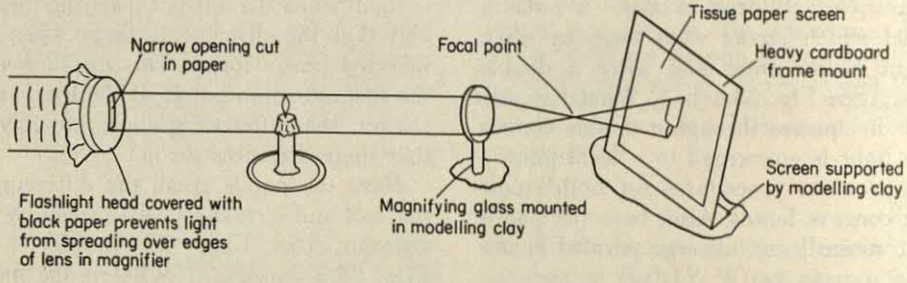

Tissue paper screen
Narrow opening cut in paper
Focal point
Heavy cardboard frame mount
Screen supported by modelling clay
Flashlight head covered with black paper prevents light from spreading over edges of lens in magnifier
Magnifying glass mounted in modelling clay

Fig. 33.7 A convex lens projects an inverted magnified image on a screen. For this reason, convex lenses are used in all projectors.

inches square, can be covered with tissue paper and used in place of the screen shown in Fig. 33.7. Let the pupils experiment to find how high and far apart they must place the screen, the lens, the object, and the source of light in order to obtain a *sharp, inverted, real image* on the screen. For best results, this experiment should be done in a darkened room.

After the class has observed the inverted, real image that appears on the screen, have them observe how the lens refracts the light to form this image. Use chalk dust to make the light visible from the source to the image. (The light will be refracted as it passes through the lens. It will converge in front of the screen. The real image will form near the place of convergence or focal point. When a real image is formed on a screen, it is called a *projected image.*)

Have the pupils arrange the convex lens and an object so they can see the magnified virtual image. (See Fig. 33.5.) Have them try to find this virtual image with the screen by placing the screen at different distances on both sides of the lens. Can a virtual image form on or be projected on the screen? (No. The only kind of image formed by a convex lens that will form on a screen is the inverted real image. All projected images are inverted real images. Upright virtual images will not appear on a screen.)

Borrow a slide projector and slides. Let the children guess how the slides should be inserted in a projector to form an *upright image* on the screen. (The slide is put into the projector in an inverted position.) Have them check their guesses by actually placing a slide in the projector and observing the result. Let the pupils observe that filmstrips and movie films also go through their projectors in an inverted position.

10. What kind of image can be seen with a concave lens? What causes this image to form?

If a concave lens is available, substitute it for the convex one and repeat all the experiences in Inquiry 9 to find out what kind of image it forms. (A concave lens forms only a *small virtual image* because this type of lens diverges light. Can this virtual image be projected on a screen? (No. Virtual images formed by lenses cannot be projected on a screen.)

11. How is light refracted when it enters and leaves a prism? How are the spectral colors separated from white light by a prism?

If the children will make a large white paper prism and apply their knowledge of refraction, they can arrive at a diagram like Fig. 29.1 which shows how the light is refracted as it enters and leaves the glass prism.

Help the class to understand why a prism separates white light into the spectral colors. (The fact that the light is refracted on entering and leaving a glass prism is only a partial answer. The white light is also *dispersed* or separated into the spectral colors as it passes through the prism. See Fig. 29.1. Call their attention to the differences in the distances that the red and violet light travel in the prism. (The violet light *is refracted more* than the red light. This causes the violet light to travel a longer distance as it passes through the prism. The red light, traveling the shortest distance, enters the air first. Yellow, green, and blue enter the air in that order. Finally, the violet light, which is refracted the most and travels the farthest in the prism, leaves the prism and enters the air.)

When lenses refract white light, they also tend to disperse or separate the spectral colors. The dispersal of light by lenses causes problems for astronomers using refracting telescopes. Refracting telescopes use convex lenses to converge to a focal point the light coming from celestial objects. Have some of the students prepare a large diagram of a refracting telescope. Concave mirrors also converge light to a focal point. (See Chap. 32, Inquiry 4.) Concave mirrors are used in reflecting telescopes. Ask another group of pupils to prepare a large diagram of a reflecting telescope. Because concave mirrors do not disperse light into the spectral colors, there is no problem of spectral colors when very large mirrors are used to "collect" the light from heavenly bodies that are located many millions of light years away from the earth.

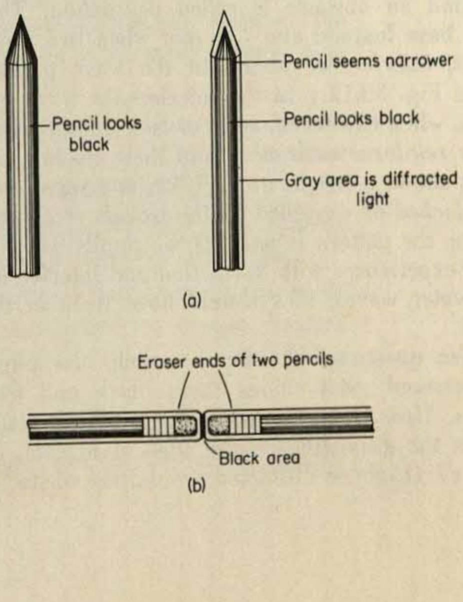
When the students are ready to explore the theory that light has wave characteristics that can be used to explain why refraction occurs, use the experiences with water waves in Chap. 35, Inquiry 7.

12. What other things besides a triangular prism can be used to separate the spectral colors in white light?

Have each member of the class hold a sharply pointed pencil in a vertical position. Tell them to hold it so they can look at the pointed end and a bright light at the same time. Tell them to close one eye as they look at them. Ask them what they see [see Fig. 33.8(a)]. (They will see a gray area—diffracted light—around the pencil. The pencil will seem narrower. It looks as if light *was* coming through the edges of the pencil.) Ask the pupils to try to explain what is happening. Use questions like these to guide them. Why can light not go through any part of the pencil? (The pencil is opaque.) What does the color gray indicate? (It indicates that some light is coming from this area to the eyes.) If the light cannot go through the pencil, how do you think the light gets to this area? (It may *bend around the edges* of the pencil.)

Ask the pupils to hold other small objects in front of a bright light to find out if they can

Fig. 33.8 (a) Light diffracted by the edges of a pencil. (b) When two diffraction bands overlap, a black area occurs where light waves from one diffraction band are blocked or canceled by waves from the second diffraction band.



see that the gray area seems to make these objects narrower. (They will.) Find out if any pupils can see that the gray area is made up of fine black lines which follow the shape of the object. (Some of them may be able to see the lines.)

Ask the students to hold two small objects at the same time in a bright light and to notice that around both there are lighted gray areas. Move the two objects close together so that part of the gray areas overlap. What happens? [See Fig. 33.8(b).] (It is black where the gray areas overlap.) What does the color black tell? (Black means *no light* is coming to the eye from this area.) Recheck to be sure the small opening between the two objects is not closed. Can the black area *really be seen when there is a small opening between the objects through which light should be able to pass?* (It can.)

Hold the metal edges of two rulers close together. Look between the metal edges of two rulers at a bright light. What can be seen? (A black line and often a series of parallel black lines can be seen.) How do scientists explain the gray and black areas and the black lines? Ask the pupils if they have had any experiences that they can use to explain the gray areas (really a series of fine black lines) and the black areas and lines. When they have the experiences in Chap. 35, Inquiry 7, they will have learned (1) that *light travels with characteristic wave motion* and (2) that water waves *bend* around obstacles. When a wave passes the edge of an obstacle, it bends, curves, and spreads out behind the obstacle. This bending and dispersing of the wave around an obstacle is called *diffraction.* They will have learned also (3) that when two waves meet, *interference* occurs in the wave pattern. (See Fig. 35.12.) In the interference wave pattern, when two wave crests or two troughs meet, they *reinforce* each other and their shadow pattern shows a bright area. When one wave crest is *blocked* or cancelled by the trough of another wave, the pattern is dark. If the pupils have not had experiences with diffraction and interference of water waves, they should have them at this time.

Use questions like these to help the pupils understand what causes these black and gray lines. How does the back light, which comes from the gray area on the edge of objects, get there? (Light is diffracted around the obstacles. Wave motion seems indicated.) How can wave motion account for the dark areas and dark lines that appear in the narrow openings between obstacles where *light should be able to pass freely?* (When one water wave blocks or cancels another water wave, the shadow of this interference pattern is dark. The black may occur where one light wave blocks or cancels another light wave.) How can wave motion account for the light areas between the dark lines? (When one water wave reinforces another water wave, the shadow of this interference pattern is light. The light areas may occur where one light wave reinforces another light wave.) If interference of *two or more* light waves causes these dark and light lines (diffraction bands or lines), how can the many fine black lines in the diffracted light in the gray area of *one* object be explained? (Not one wave but many waves are being diffracted by the object.)

Darken the room. Make a very small hole with the point of a fine needle in a piece of black construction paper. Hold the paper in front of a lighted candle so the light will pass through the hole and fall on a white screen several inches beyond the black paper. Observe the *very large spot* of light that appears on the screen. Let the children explain why the spot of light is so much larger than the tiny hole through which the candlelight passes. (The light is diffracted, spread out, or dispersed as it passes through the small opening in the paper.)

Cut a slit in the black paper with a razor blade. Allow light to pass through the slit to the screen. Observe the dispersed light on the screen. The dispersal is caused by *diffraction.* If the slit opening is very narrow, bands of colors may be seen on the screen. In the black paper, cut two slits very close together. Adjust the candle so its light shines through both slits onto the screen. What evidence of diffraction can be seen? (The light passing through each slit is dispersed. Bands of color can be seen.)

Have the children look at a bright light or a street light through a thin, white handkerchief. Also have them look at this light through a piece of fine mesh window screen. Tell them to squint their eyes as they do this. They will see colors caused by the diffraction of the different wave lengths (colors) in white light. Red will appear if the diffracted *red wave* lengths in white light reinforce each other. If these wave lengths block or cancel each other, red will not appear. The same explanation applies for each of the wave lengths.

Ask some of the children to read and report about the prism and the diffraction grating spectroscopes used to study the composition of chemical compounds, chemical mixtures, and heavenly bodies. Ask these pupils to be prepared to explain why spectroscopes are such important tools for astronomers and chemists. (See Chap. 23, Inquiry 4.) When the students are ready to explore the theory that light has wave characteristics which can be used to explain why diffraction and interference effects occur, use the experiences with diffraction of water waves in Chap. 35, Inquiry 8.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. An object that is partially submerged in water appears to be bent at the water's surface *if you look at it from the side*. When you look from the side at objects or parts of objects that are submerged in water, they appear *also to be shorter and wider* than they really are. Objects that are completely submerged or partially submerged in water appear to be about normal in size and shape *if you look straight down into the water at them.*

2. When a slanting beam of light enters and leaves water, it is refracted at the surface of the water. Slanting light beams are refracted toward the normal when they enter water. Slanting light beams are refracted away from the normal when they leave the water. Perpendicular light beams are not refracted when they enter or when they leave water.

3. Light is refracted where it enters and again where it leaves plate glass. On entering it is refracted toward the normal, and on leaving it is refracted away from the normal.

4. A slanting beam of light is refracted when it enters and leaves many transparent media. Some liquids refract a light beam more than water does.

5. Different transparent media have different densities. The speed of light is decreased in more dense transparent media and increased in less dense media.

6. A slanting beam of light is refracted *toward the normal* when it travels *from a less to a more dense transparent medium*. It is refracted *away from the normal* when it travels *from a more dense to a less dense transparent medium*. The speed of a beam of light *decreases* when *it enters a more dense medium* and *increases* when *it enters a less dense one*.

7. Refraction of light causes the illusions that make objects appear to be located where they are not. Mirages are caused by the refraction of light as it passes from a layer of cool dense air to a layer of less dense warm air.

8. Lenses refract light. Both convex and concave lenses refract light. Convex lenses converge parallel beams of light, and concave lenses diverge them.

9. Convex lenses form both real and virtual images. The virtual image is the magnified image that makes convex lenses useful as magnifying glasses. Because the real image can be projected on a screen, convex lenses are used in all projectors.

10. Concave lenses form *only small upright virtual images*. The light which passes through a concave lens is diverged by refraction. A concave lens cannot project an image on a screen.

11. A triangular prism *refracts* white light and *disperses* it into its spectral colors. The *shape* of a triangular prism causes each spectral color in white light to be refracted at a slightly different angle from each of the other colors. The differences in the *size* of the angles cause *differences* in the *distances* that each of the colors travel through the glass. The prism separates, or *disperses,* white light because each of the spectral colors leaves the prism at a different time. The red wave length is refracted the least, has the shortest distance to travel through the prism, and enters the air first. Violet is refracted the most, has the longest distance to travel through the prism, and enters the air last.

12. Light waves are *diffracted* (bent, curved, and spread out) when they pass through small openings. Light waves are also diffracted by the sharp edges and grooves of some objects. When diffracted light waves meet, there is an interference effect. Interfering waves either reinforce or cancel each other. Interference resulting from diffraction causes the light and dark bands and also the presence or absence of certain colors.

Chapter Thirty-Four

Our Eyes and Theories of How We See

INQUIRIES

1. What are some of the ways in which our eyes and cameras are alike? What are some of the ways in which they differ?

2. How are our eyes thought to react to light and color?

1. What are some of the ways in which our eyes and cameras are alike? What are some of the ways in which they differ?

Give the children the opportunity to examine a camera that has no film in it. Have the class locate the important parts of the camera and discuss the function of each.

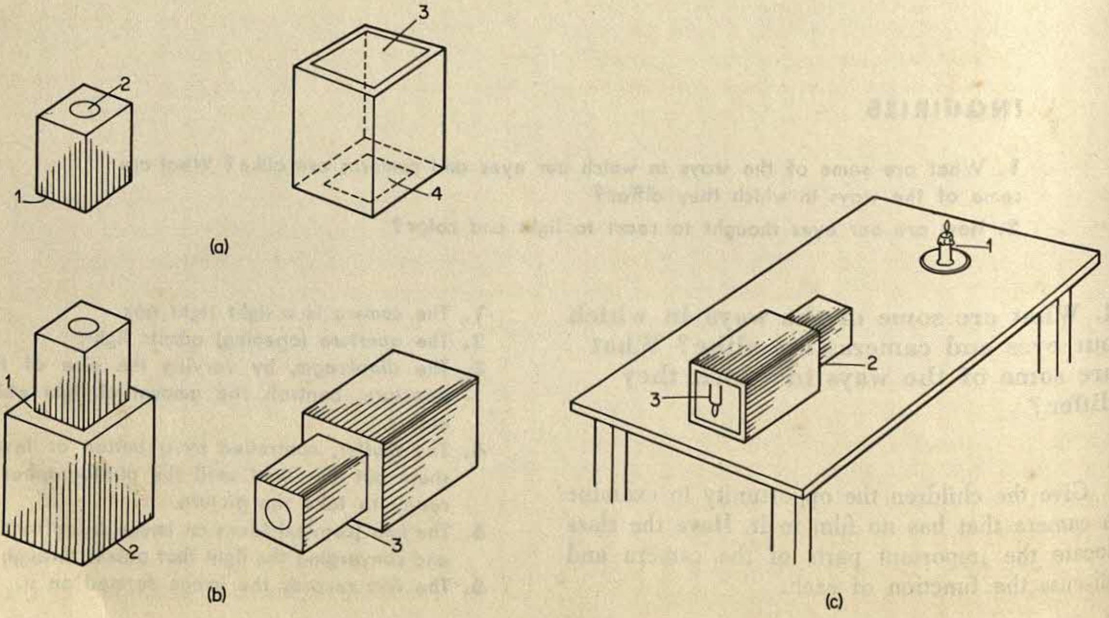
1. The *camera* is a light tight box.
2. The *aperture* (opening) admits light.
3. The *diaphragm*, by varying the size of the aperture, controls the amount of light which enters.
4. The *shutter*, controlled by a button or lever, shuts out the light until the photographer is ready to take the picture.
5. The *lens* (convex) forms an image by refracting and converging the light that passes through it.
6. The *film* records the image formed on it.

Open the loading end of the camera. Hold the front of the camera toward a bright light (a sunny window or a lamp). Have the children look into the camera from the open end. Be sure they observe that no light enters the front end of the camera. Set the camera control for a *time exposure* and press the button or lever to open the aperture. Look at the light through the open aperture. While the aperture is being held open by the time exposure control, show the pupils how the diaphragm changes the size of the aperture. They should be able to see the difference in the size of the aperture when the diaphragm is moved first to its largest and then to its smallest opening. Discuss with the pupils the need for a diaphragm. (One way a photographer can control the amount of light reaching the film is to use the diaphragm to control the size of the aperture. When the light from either an area or subject to be photographed is intense, too much light could reach the film through a large aperture. When the light from the area or subject is dim, too little light could reach the film through a small aperture. At this time, the photographer can use the diaphragm to make the aperture larger.)

Change the shutter from time exposure to any one of the shutter speeds used for taking snapshots. Set the diaphragm at its largest opening. Again hold the front of camera toward the light. While the pupils take turns looking into the back of the camera, press the button or lever that activates the shutter. Call attention to the flash of light that can be seen through the aperture between the time the shutter opens and closes. Reset the diaphragm to its smallest opening and repeat. (Less light enters the camera because the diaphragm has made the aperture very small.)

Set the diaphragm midway between its largest and smallest size. Set the shutter speed for the longest time the camera permits for a snapshot. Have the children observe the time between the shutter's opening and closing. Reset the shutter speed for the shortest time. Compare this time interval between the opening and closing of the shutter with the previous time interval. How

Fig. 34.1 How to make a focusing camera. (a) Paint interior of both boxes with dull black paint. 1. Remove bottom of smaller box. 2. Cut opening slightly smaller than convex lens and tape lens in position over opening. 3. Cut opening in one end of larger box and tape tissue-paper screen in position over opening. 4. Cut opening the size of small box in other end of this box. (b) 1. Fit smaller box snugly into larger box. 2. Tape screen on bottom of larger box. 3. Small box slides in and out of larger box. (c) Back view of camera. 1. Place candle at distance necessary to obtain image on screen. 2. Move small box in and out of larger box until a *sharp* image forms on screen. 3. Inverted image forms on screen.



does the time between the opening and closing of the shutter control the amount of light that enters the camera? (More light can pass through the aperture when the aperture is open longer.) In what two ways can the amount of light entering a camera be controlled? (The *size* of the aperture, controlled by the diaphragm, and the *length of time* the aperture is open, controlled by the shutter speed, determine how much light enters a camera.) Be sure the pupils realize that even with the largest diaphragm opening and the longest shutter speed the amount of light that enters a camera is still very small. This may help them build an appreciation for the sensitivity of film. (Film records an image with a small amount of light.)

Some of the children may enjoy making a focusing camera that will enable them to see a real image of the scene that is in front of the lens. See Fig. 34.1 for instructions for making a focusing camera. After they have had fun focusing the lens and observing a number of images, they may wish to convert this camera into one that can record the image on film. This can be done by making two changes:

1. The translucent screen in the back of the camera must be covered with heavy black paper to make the camera lightproof.
2. The camera must have a shutter. The shutter should meet these specifications:
   - (a) It must be lighttight.
   - (b) It must have some means for opening and closing it without jarring the camera box.
   - (c) It must be placed in a position where it can be operated without interfering with the light that enters the lens.

Encourage the children to try to invent a shutter for their camera. If they are not successful, a very simple one can be made from two paper cups (see Fig. 34.2). Cut off the upper part of cup A to use for a *lens hood.* Use cup B for a *combination lens cover and shutter.* Paint the inside and outside of both the lens hood and combination lens cover and shutter with dull black paint. Paste the rim edge of the lens hood paper cup to the cardboard around the camera lens. Push the lens cover paper cup over the hood and check to make certain that no light leaks through it into the camera. If there is a light leak, wind black tape around the lens hood and check again. Repeat this procedure until the lens cover makes a tight seal against the hood. Have the pupils make believe that they are taking pictures and practice removing the paper cup shutter *without putting their fingers in front of the lens* and *without jarring the camera.* (This can be done by holding the camera firmly with the left hand, and with the right hand, pulling the cover outward and then upward and over the top of the camera box.)

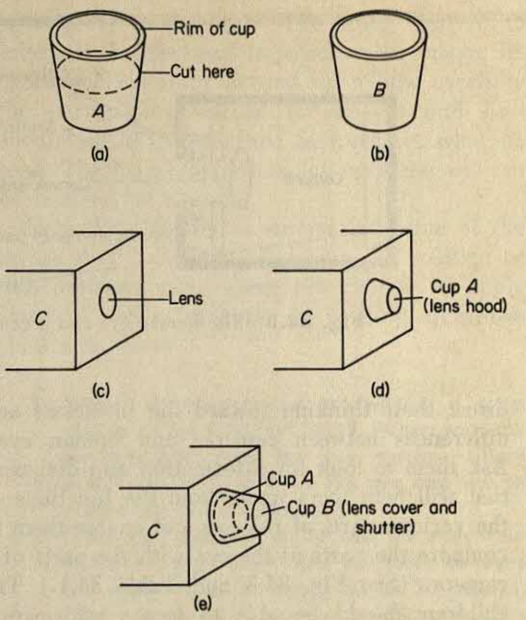


Fig. 34.2 Directions for making a lens hood and a combination lens cover and shutter. (a) Use upper part of cup *A* for lens hood. (b) Use cup *B* for a combination lens cover and shutter. (c) Focusing camera box. (d) Cup *A* pasted in position with rim of upper part of cup toward camera. (e) Cup *B* fits tightly over lens hood (cup *A*).

Help the class make plans for inviting a photographer to assist them in taking their first picture. They may also need his assistance in (1) the selection of a type of sheet film that has low light sensitivity (slow emulsion speed); (2) finding out how to load the film in complete darkness (how to tape the film to the screen on the inside of the camera); (3) arranging suitable lighting; (4) timing the exposure of the film to the light which is the interval between the opening and closing of the shutter; and (5) unloading the film in darkness and getting it processed.

Give the pupils the opportunity to evaluate their experiences with the focusing camera, and

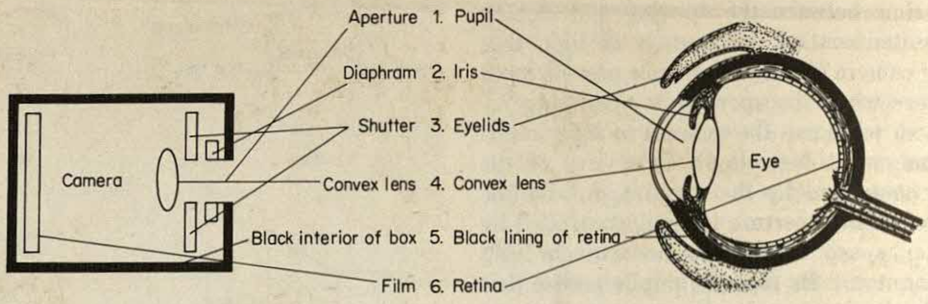


Fig. 34.3 The human eye and a camera have six parts that are similar in function.

direct their thinking toward the likenesses and differences between cameras and human eyes. Ask them to look for information and diagrams that will help them understand the functions of the various parts of the eye and enable them to compare the parts of the eye with the parts of a camera. (See Fig. 34.3 and Table 34.1.) The children should be able to locate information similar to the following:

> **The Pupil.** Light enters the pupil of the eye. The pupil is an opening in the front of the eye covered by the cornea. The pupil is the dark spot or hole in the eye.
>
> **The Iris.** The iris controls the size of the pupil. The iris contracts in dim light. When it contracts, it increases the size of the pupil. In bright light, the iris expands and decreases the size of the pupil. When the pupil of the eye enlarges, more light passes through it; when it decreases in size, less light passes through it.
>
> **The Lens.** The double convex lens in the eye refracts the light passing through it and converges the light to a focus, and an image forms on the retina.
>
> **The Retina.** On the retina an inverted real image *is said to form.* Actually, the focused light beams stimulate nerve cells in the retina causing them to produce electrical impulses. These impulses travel through the optic nerve to the visual center of the brain. The nerve cells in the brain, stimulated by the electrical impulses, convert the impulses into an *upright image,* and *the sensation of seeing is produced.*

Ask several of the pupils to make a large diagram of an eye similar to the one in Fig. 34.3. Also, ask another group to make a large diagram of a camera similar to the one shown in the same figure.

These guidelines may be useful in leading a discussion about the likenesses and differences between eyes and cameras. A healthy human eye makes *automatic adjustments* that the most complex camera cannot make even when it has the most recent precision and electronic devices. Help the children list and discuss the differences that follow.

1. The convex lens in the healthy eye of a young person can bring to a focus (see clearly)

Table 34.1

THE HUMAN EYE AND A CAMERA HAVE SIX PARTS THAT ARE SIMILAR IN FUNCTION

Number	Eye	Camera	Function of Parts
1	Pupil	Aperture	Opening through which light beams travel
2	Iris	Diaphragm	Controls amount of light entering
3	Eyelid	Shutter	Opens and closes to admit light
4	Convex lens	Convex lens	Refracts and converges light to a focal point
5	Black lining of retina	Black interior of box	Reduces reflection
6	Retina	Film	Reacts to light rays and registers image

objects at different distances. The lens can do this because its thickness and curvature can be changed. Attached to the lens of the eye by ligaments are ciliary muscles. When the ciliary muscles contract, they force the ligaments to relax. This allows the lens to thicken and become more convex. When the muscles are relaxed, the lens and the eye are said to be in a relaxed or at rest position. In this position the less convex shape of the lens keeps in focus all objects that are 20 feet or more away. When objects are closer than 20 feet, the ciliary muscles adjust the lens in the eye to the degree of thickness that will focus clearly any object between 20 feet to 10 inches.

Some simple cameras have a fixed convex lens. This means that pictures of objects 8 or more feet away will be in recognizable focus. However, objects that are closer than 8 feet will be out of focus. More complex cameras have an adjustable focusing device, which is operated by the photographer. This device decreases and increases the focal distance between the camera's convex lens and the film by moving the lens nearer or farther away from the film. Invite a person who owns a camera that has an adjustable focus to show the pupils how the focusing device operates.

2. The *iris* of the eye automatically increases or decreases the size of the opening or pupil. Shine the light from a small flashlight close to the eyes of one child. Have the other children observe how the light causes the pupil in the eye to *decrease* in size as the iris expands. Compare this experience to the ones the children have had when they enter a brightly lighted room at night or when the lights in the theater flash on at the end of a movie. Also, observe the increase in size of the pupil and the contraction of the iris when the light is removed.

Most cameras have a diaphragm, which is either mechanically or electronically controlled. If the photographer who visits the classroom to show the class his adjustable focusing camera has an electronically controlled diaphragm on his camera, ask him to demonstrate how it operates.

3. *A real image seems to form on the retina of the eye;* it only seems to form there. Actually, the nerve cells in the retina produce electrical impulses when they are stimulated by focused light beams. These impulses travel through the optic nerve to the brain. The brain "learns" to interpret the electrical impulses as an image. Its detail and accuracy depend upon how carefully the person has learned to observe and how accurately he has learned to interpret what he sees. These interpretations or impressions can be recalled on demand.

Help the children to summarize some of the things they have learned during the solution of this problem. Give them the chance to apply some of their learnings by asking questions similar to these:

1. Why is it more restful to study in a room that is at least 20 feet long? (When you look up from your work, the eye muscles—ciliary muscles—relax and cause the eye and lens to assume an at rest position.)
2. What can a person do to rest his eyes if he works in a small room? (He can close his eyes for a minute or so every 20 or 30 minutes. Closing the eyes also causes the ciliary muscles to relax.)
3. Why should a room used for studying be well lighted? (A well-lighted room reduces eye strain. If only a study lamp is lighted in the room, the iris in the eye will contract each time the person looks away from his work and expand each time he resumes his work.)
4. Why is a proper diet important for maintaining good eyesight? (The different kinds of cells in the eye (muscle, nerve, blood cells, and the membranes—must have proper nourishment to function properly.)
5. Why is a person likely to have a headache after studying for long periods of time in a poorly lighted room or after being out in the bright sunlight without proper protection for the eyes? (Eye muscles and nerves become fatigued.)
6. Why should a person protect his eyes when he is sunbathing? (To prevent his eyes from becoming sunburned. Sunburn causes the formation of scar tissue, which reduces the transparency of the cornea to sunlight. Repeated overdoses of sunlight are believed to be one cause for blindness.)

2. How are our eyes thought to react to light and color?

Help the children locate information about the light sensitive cells in human eyes—the different color theories that propose explanations

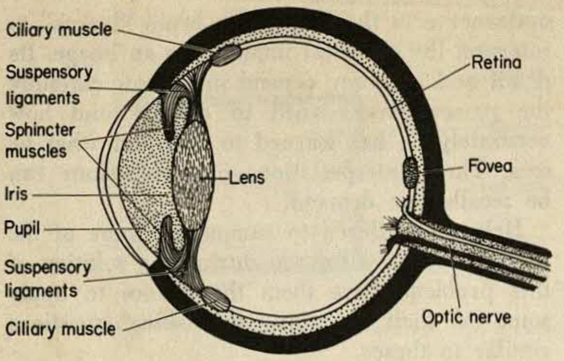


Fig. 34.4 Cross section of eye showing fovea where cones are located.

concerning how human eyes "see" color. Encourage them to look for and try experiments which will provide evidence to support the color theories. Encourage the pupils to record the title, author's name, publishing company's name and address, publication date, and the page numbers on which they find information pertaining to the inquiry. The pupils should also make brief notes of the information they find in their reference reading. The notes will enable them to share their information with the class. The paragraphs that follow contain some of the information that the class may find and wish to discuss.

There are about 139 million sight-receiving cells located in the retina of the human eye (see Fig. 34.4). These cells are classified into two types on the basis of their shape and function; *rod cells* and *cone cells.* The rod cells react in *dim light to shapes and movement.* Cone cells react to strong light and to both color and the small details of objects. The cone cells are largely confined to a small area of the retina called the *fovea.* The fovea does not contain rod cells. These cells are located throughout the retina. (Use this information to help the children explain why colors disappear in semidarkness.) Some of the cone cells are believed to react to long wave lengths in light (red) and others to shorter ones (green and blue).

There is much that is not known about color sensations, but there are several different theories that propose what causes them. Even though none of these theories are completely acceptable, they are useful in stimulating research. Each theory proposes that color sensations are attributable to the presence of cone cells in the retina of the eye. Three of the color perception theories are described briefly in the next three paragraphs.

1. Young-Helmholtz Theory. There are three different kinds of cone cells. One kind is sensitive to *blue light,* a second to *green light,* and a third to *red light.* The yellow sensation is produced by equal stimulation of the red and green sensitive cone cells. (This theory cannot be used to explain how a person who is color-blind to red and green can see yellow.)

2. Hering Theory. There are three kinds of *double* acting cone cells. The first kind is sensitive to both *blue and yellow light;* the second is sensitive to *green and red light;* and the third is sensitive to stimulation by *black and white.* Light reflected from blue, green, and black objects is thought to build up chemicals in the cone cells. Light reflected from yellow, red, and white objects is thought to break down the chemicals in the cells. (Some people question this theory because it pairs red and green in the same double-acting cells. Red and green are not considered to be complementary colors.)

3. Ladd-Franklin Theory. According to this theory, the largest color zone is *blue* and the next largest is *yellow.* The *red* sensitive and *green* sensitive zones are much smaller. The presence of a large yellow color zone explains why color-blind persons can see yellow when they cannot see red and green.

One of the simplest and most frequently used explanations is the Young-Helmholtz theory. This theory proposes that human eyes are sensitive to three colors of light—red, blue, and green and that all other colors are combinations of these three colors. (Review Chap. 29, Inquiry 6.) In this inquiry, the learning that *an illusion of white can be produced from a combination of red, green, and blue light is developed.* It also shows that *a wide variety of other colors can be produced by mixing varying amounts of these three colors of light.*

The class may like to do this test which is used as evidence to support the Young-Helmholtz theory. Obtain three-inch pieces of red, green, and blue colored paper. The colors of these papers should be as close as possible to the *pure colors* of red, green, and blue in the spectrum. Hang a white paper screen on the wall and arrange the children so that they are as close to the screen as possible. Direct the beam of a slide projector on the screen. Ask the pupils to gaze intently at the screen for about 30 seconds and then to close their eyes. They will sense a bright spot in their eyes. This bright spot is called an after-image and it will persist for about *half a second.*

Hold the red piece of paper against the screen and shine the beam of white light on it. Look at the red paper for about half a minute and then remove it. An after-image will form on the screen as soon as the red paper is removed. The after-image will appear to be *cyan blue* (blue + green light). It may take a little practice before some of the children will be able to see the after-image, because it fades in approximately one-half second. Continue the experiment with the green and then the blue pieces of paper. Their after-images will be *magenta red* (red + blue light) and *amber yellow* (red + green light).

According to the Young-Helmholtz theory, each of the three after-images was caused by the failure of a different group of color sensitive cone cells to respond to the white light shining on the screen. The red sensitive cone cells were too tired to react to the red wave length in white light after the red paper was removed. This caused the color of the after-image to appear to be *cyan blue* (blue+green) or white minus red. The green sensitive cells were too fatigued to respond to the green in white light when the green paper was removed. The after-image was *magenta red* (red+blue) or white minus green. The blue sensitive cone cells failed to respond to the blue in white light after the blue paper was removed. This caused the after-image to appear to be amber yellow (red+green) or white minus blue. (See Figs. 29.4 and 29.5.) On the basis of the three observations made of after-images, the pupils should be able to form a conclusion similar to this one: the after-image test does provide *some evidence* that supports the Young-Helmholtz theory.

Some of the children may have heard about a recent discovery that seems to indicate that color sensitivity *may not be confined to the eyes.* It was found that some people can learn to detect color differences with their fingers and other parts of their bodies. Your pupils may enjoy finding out whether with *their fingers* they can learn to distinguish between colors. They will need a "lighttight" box about two feet by three feet with two holes in it large enough so that they can insert their hands. Let them experiment with colored papers and crayons. The papers should all be the same size and have the same weight and texture. The crayons should be the same size and unused. Start with only a few colors, such as red, blue, yellow, and green. Allow the children to feel and handle the samples freely before the test. Before taking the test, the class should plan a procedure containing steps similar to these:

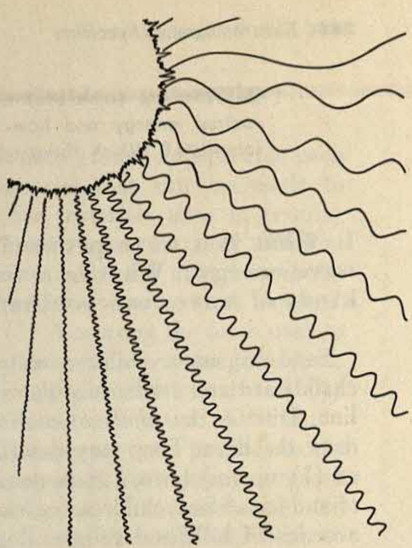
1. The colored samples should be placed in compartments on the floor of the box.
2. The sequence of the different colors should be known only to the teacher.
3. The class should be divided into small groups and a leader chosen for each of the groups. The leader should not only be in charge of his group, but should also record color identifications made by each child in his group.
4. Each pupil taking the test should insert his hands in the box, feel each of the samples, and then, starting at the left end of the box, tell what color he thinks each sample is.
5. Each child's decision should be recorded on paper by the leader of each group. Care should be taken that only the leader can hear a child's responses.
6. Reveal the order of colors in the box to the class. Underline each color that each child correctly named.
7. To make certain that a child's correct identification of a color or colors was not an accident, the tests should have been repeated several times, with new arrangements of the colors. (It is possible that some of the children can repeatedly identify one or more colors with their fingers. As many as 15 per cent of the adult groups tested have been found to have this color sensitivity in their fingers. Encourage the children to look for more information about these studies. These studies may lead to the discovery of an unknown part of the color spectrum or to other light sensitive cells in the body that enable some people to learn to "see" with their fingers or even with other parts of their bodies.)

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. The human eye is like a camera in a number of ways. A *real image* forms on the film in a camera. A *real image appears to form* on the retina of the eye. Actually, the nerve cells in the retina produce electrical impulses when they are stimulated by light beams. These impulses travel through the optic nerve to the brain. The brain "learns" to interpret the electrical impulses as an image. Both the camera and the eye have a lens. The eye has ciliary muscles that enable its lens to change shape in order to accommodate or to focus on objects at different distances. Most cameras can be focused on objects at different distances by a device that moves the lens closer to or farther away from the film.

2. There are many millions of light sensitive cells in the retina of the human eye. Light sensitive cells are classified into two types—rod cells and cone cells. Rod cells react in dim light to the shape and movement of objects. Cone cells react in bright to the color and small details of an object.

There is much that is not known about how our eyes react to color. Research is going on to find out why some people can sense color or "see" with other parts of their bodies besides their eyes.



Chapter Thirty-Five

Electromagnetic Spectrum

Electromagnetic Waves

INQUIRIES

1. What is a wave pattern? What is wave energy? What is a wave? What kinds of waves can you name?

2. What are the parts of a wave called?

3. How are all visible waves alike?

4. How is a wave measured? What causes the amplitude of waves to vary? What is meant by the term velocity? What is wave frequency? What is the relationship between wave length and frequency?

5. What is the mathematical relationship between wave velocity, wave length, and wave frequency? Why is this relationship important?

6. How do scientists classify radiant energy? In what ways is all radiant energy alike? How does it differ?

7. How many wave characteristics of radiant energy can be demonstrated in differently shaped swimming pools?

8. How do electromagnetic wave energy and mechanical wave energy differ? What are some of the characteristics that both waves and particles have in common?

9. Who are some of the scientists who have advanced theories about the nature of radiant energy and how it travels? What was the contribution of each of these scientists? Which theory is currently acceptable?

1. What is a wave pattern? What is wave energy? What is a wave? What kinds of waves can you name?

Send as many children as you can to the chalkboard and ask each of them to draw a wavy line. Discuss the *kinds of motion* they used to draw the lines. They may describe their motion as (1) up-and-down, (2) back-and-forth, or (3) to-and-fro. Some children see the wavy lines as a series of hills and valleys. Recall that objects must vibrate (move to-and-fro) to cause sound. (See Chap. 16, Inquiries 2, 7, and 11, and repeat the experiences with tuning forks.) What *kind of motion* does a vibrating tuning fork make? (A back-and-forth or to-and-fro motion.) When the prongs of a vibrating tuning fork touch the surface of water, what *kind of motion* can be seen in the water? (An up-and-down motion.) When the vibrating tuning fork is moved so it traces a wavy line on smoked glass, what *kind of motion* produces the wavy line? (The back-and-forth or to-and-fro motion of one of the tuning fork's vibrating prongs.) Make certain that children understand that such up-and-down, back-and-forth, or to-and-fro motions are called *vibrations* and also that the wavy lines on the chalkboard and on the smoked glass are wave *patterns.*

Next ask the children what they used to draw the wavy chalk lines? (The *energy* in the muscles of their arms and hands.) What is needed to vibrate a tuning fork? (*Energy* is needed. When one of the prongs of the tuning fork is struck by a rubber mallet, energy is transferred from arm muscles to the mallet and from the mallet to the tuning fork.) What caused the surface of the water to be disturbed (move up and down) when it was touched with the vibrating prongs of the tuning fork? (*Energy* caused the disturbance. The energy of the vibrating prongs was transferred to the water.) Why could the vibrating tuning fork trace wavy lines on smoked glass? (It had *vibratory energy.* This energy made the wavy lines.) The children should conclude that *energy* is necessary to produce vibratory motion (up-and-down, back-and-forth, or to-and-fro motion).

The following experiences will help to develop the concept that vibratory energy that travels from one point to another is called *wave energy.* Plan a work period in which *each member of the class* can try different methods of using vibratory energy to produce visible disturbances in materials (media). Such materials as pans of water, flexible rope, rubber tubing, coiled spring curtain rods, and Slinkys (coiled spring toys) are readily available for experimentation. Tie one end of the material, tubing, or coiled spring to a door knob. Shake the loose end up and down or to and fro. Be sure the pupils understand that they are vibrating these materials and that they are causing vibratory energy to travel through the different media. Ask them what they see. (They see these materials vibrate up and down or to and fro. In each material, they see a wave pattern caused by a disturbance. The vibratory energy or disturbance that has traveled through the media is called *wave energy.*) Make certain the pupils also see the up-and-down motion of water when wave energy travels through it. Hold the loose end of the coiled spring in one hand, and with the other hand, pinch together a number of coils. Release the tension (energy) in the compressed coils. Watch the back-and-forth disturbance move through the spring.

Shake the rope up and down *just once.* Notice: (1) that the first up-and-down disturbance of the rope produces a second, a third, a fourth, and so on, up-and-down disturbance through the length of the rope; (2) that the rope is displaced upward and downward; and (3) that the rope only *seems* to move in the direction in which the wave energy is traveling. Tie a white string around the rope and watch the string as the experiment is repeated. The string moves up and down *but not forward.* Vary this experiment to apply it to water. Float a small object on the water. Watch the object move up and down but not forward as the wave energy travels through the water. (Actually the molecules in liquids and in gases may not return to their original positions after wave energy has traveled by them.)

What is a wave? It is a disturbance caused by wave energy. The disturbance is characterized by either an up-and-down or a to-and-fro motion. The disturbances or waves the children have seen in water, rope, tubing, and springs have been visible waves. The disturbances or waves that sound produces in air are invisible waves. Have the class list all the visible and invisible waves they can. They may list many of these.

VISIBLE WAVES	INVISIBLE WAVES
Motion of flag	Sound waves
Clothes swinging back and forth on clotheslines	Earthquake waves
	Light waves
Swaying of leaves, branches and trees on a windy day	Heat waves
	X-rays
Waves on surface of bodies of water	Radio waves
	Television waves
	Electric waves

2. What are the parts of a wave called?

In Chap. 16, Inquiry 7, it was shown that a vibrating tuning fork could produce visible up-and-down waves in water, and the concept was developed that the same tuning fork produced invisible back-and-forth (compression) waves in air. All waves (whether they are visible or invisible, vibrate up and down or back and forth) are represented by wavy lines like a cross section through the surface of water waves. Such a diagram is a *wave model.*

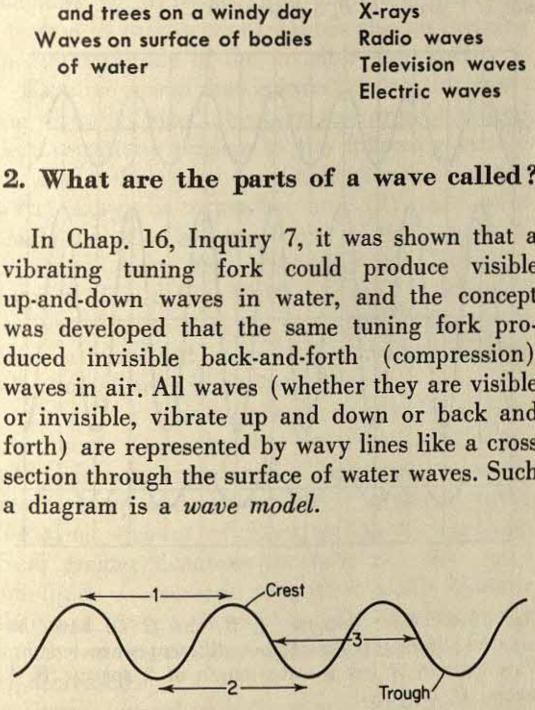


Fig. 35.1 Wave length is a measure of the distance (1) from one wave crest to the crest of an adjacent wave, (2) from the trough of one wave to the trough of an adjacent one, or (3) between similar parts of adjacent waves. The highest point in a wave is called a *crest;* the lowest point, the *trough.*

Draw a wave pattern on the chalkboard and ask the pupils to suggest a name for the peaks or tops of the waves. (See Fig. 35.1.) Write the words "crest" and "trough" on the wave pattern to indicate where each is located. Ask the children to use these words whenever they refer to either of the two parts of a wave.

3. How are all visible waves alike?

Divide the class into groups and provide each group with a material that can be made to vibrate visibly. (See materials used in Inquiry 1.) Direct each group to try as many different ways as they can to make the material vibrate and both to *feel and to observe* what happens. Suggest they try (1) *increasing* the force used to produce the vibrations; (2) *decreasing* the force used; (3) *slowly* applying the force; and (4) *rapidly* applying the same amount of force.

Ask each group to report their findings to the class. As the groups make their reports, record each finding briefly on the chalkboard and underline the key words that will help them to decide what common factors waves have. Their findings may be similar to the following ones: Water waves have crests and troughs. Waves in ropes have crests and troughs. Waves are vibrations. We could feel the wave energy as it traveled through the different materials. We made *large* waves and *small* waves. Some waves were *higher* than others. Sometimes we produced *more* waves than at other times. Some waves *seemed to travel faster* than others. (If the children do not qualify their finding that some waves *seemed to travel* faster than others, discuss the reason why this qualification is necessary. See Inquiry 1.) It did not take the wave energy very long to travel through the material.

Help the pupils to select from their finding the things (characteristics) that waves have in common. From similar findings children have recognized two common factors and in their own words have identified them as "size" and "speed."

4. How is a wave measured? What causes the amplitude of waves to vary? What is meant by the term velocity? What is wave frequency? What is the relationship between wave length and frequency?

After the pupils have reached the tentative conclusion that waves *seem* to have "size" and "speed," ask each child to choose one of these two factors for intensive study. Pupils who have chosen the same factor may wish to work together in a study group to prepare and present

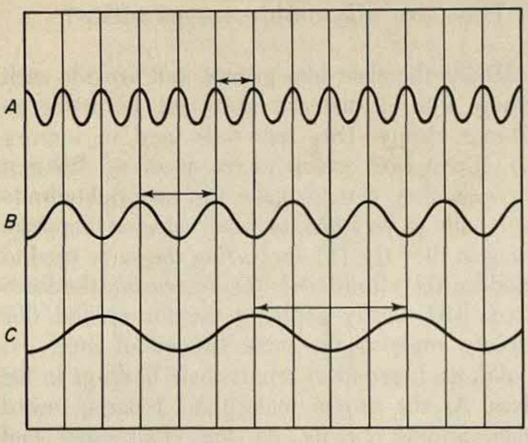


Fig. 35.2 Wave patterns *A*, *B*, and *C* have different wave lengths. In wave pattern *A* the wave length is 1 space; in *B*, 2 spaces; in *C*, 4 spaces. Of these patterns, *A* has the shortest wave length and *C* the longest wave length.

a joint report and demonstration. Those pupils who wish to work alone should be encouraged to do so and to report their findings. Remind the pupils that the words "size" and "speed" are their own and that, even though they seem to clearly express the ideas the pupils are to investigate, these words may not necessarily be the correct terms to use. Encourage the pupils to continue to use experimental materials and to consult many reference sources. Stress the need for their reports to be simple and clear and to contain helpful visual materials, experiments, and demonstrations.

Wave Length. Pupils who are concentrating on an investigation of wave "size" should contribute information and visual material similar to Figs. 35.1 and 35.2. They also should provide the information given in these figures and be encouraged to prepare and to demonstrate different wave lengths with experimental materials.

Wave Amplitude. In their search for information about "size," the pupils will probably discover and report on the *amplitude* of a wave. (See Figs. 35.3, 35.4, and 16.10.) They can use the same equipment they used in Inquiry 1 *to show* that the amplitude of *visible* waves increases and decreases as the energy increases and decreases. Pupils can relate the increase or decrease in amplitude of *invisible sound waves* to the increase or decrease in energy used, by repeating the experiment in Chap. 16, Inquiry 17 and observing changes in amplitude similar to those in Fig. 16.10. Make certain the pupils *hear* the *louder* sound produced by the tuning fork when increased energy has caused it to have increased amplitude.

In Inquiry 1 the children's list of invisible waves contains light waves. What happens when the energy used to produce the invisible light

Fig. 35.3 Waves in patterns *A*, *B*, and *C* have different amplitudes. At the same time they have the same wave lengths (2 spaces). In wave pattern *A* the amplitude is 1 space; in *B*, 3 spaces; in *C*, ½ space.

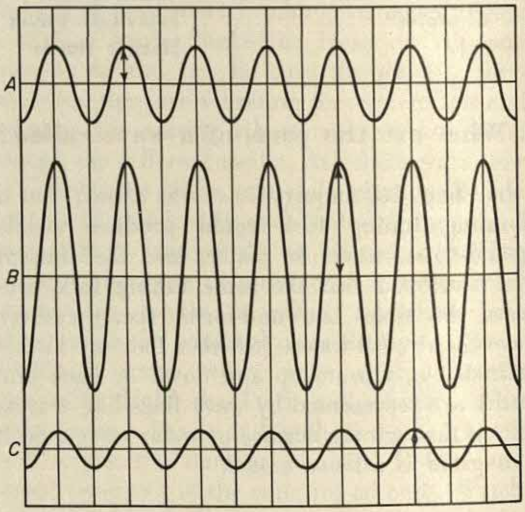
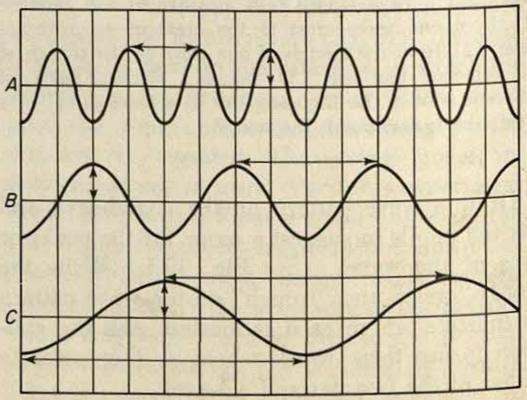


Fig. 35.4 Wave patterns *A*, *B*, and *C* all have the same amplitude (1 space), but different wave lengths. Wave pattern *A* has a wave length of 2 spaces; *B*, 4 spaces; *C*, 8 spaces.



waves is increased? The children may theorize that the amplitude of the light waves will be increased. However, because light waves are invisible, the amplitude would also be invisible. What *can be observed* when the energy is increased? Let the children try to plan an experiment to answer this question. Light a 1½-volt flashlight bulb with one size D dry cell. Then light the same bulb with two size D dry cells wired in series. Compare the results. Help the pupils to conclude that increasing the energy increases the *brightness of the light,* similar to the way increasing the amplitude increases the *loudness of a sound,* and therefore, that the increase in brightness of light is also an increase in the amplitude of the invisible light wave.

Have the group that is investigating the meaning of wave "size" also plan and present several demonstrations similar to the following one to show (1) that *wave amplitude decreases* as the wave energy is expended and (2) that *wave length remains constant* even as the amplitude decreases. Vary the experiment in Chap. 16, Inquiry 17 and Fig. 16.10 to show (1) decrease in wave amplitude as the tuning fork's energy is expended and (2) constant wave length even when amplitude is decreased.

Tie a long rope to a rigid support such as a door knob. Hold the first two feet of the rope, which is near the door, in one hand and jerk the rope up and down. Try to continue using the same amount of force to vibrate the rope from greater distances to show (1) that wave amplitude *decreases* in proportion to the distance the wave energy travels, and (2) that the wave length remains *constant* even when the amplitude is decreased.

Fasten several coiled springs together. Use a piece of string to tie one end of the joined springs to a door knob or other rigid support. Hold the opposite end of the joined springs taut and start a series of compression waves. (See Inquiry 1 for directions.) Be sure the pupils *see:* (1) that the compression wave weakens and the wave energy decreases as the distance it travels increases and that, as a result, the wave amplitude must be less; and (2) that the wave length remains constant. Encourage the reporting group to try to demonstrate these two results with water waves.

Make certain that the group reporting on wave "size" explains clearly why waves are measured by their *length* rather than by their amplitude. (*Wave length remains constant* in a medium of the same density. Wave amplitude *varies* as the distance from the source of the vibration increases.) Make certain that the pupils who listen to the report *also understand* that this is the reason why waves are measured by their *wave length* and not by their amplitude.

The remainder of the pupils in the class, who are concentrating on the investigation of "speed," will discover that they have two terms to clarify—*velocity* and *frequency.*

Velocity. Reference books will establish these facts about the velocity of sound, light, and other electromagnetic energy.

1. *Velocity of Sound Energy:*
   a. Energy that produces sound waves travels approximately 1100 *feet* per second at sea level through still air which is at 32°F.
   b. Energy which produces sound will not travel through a vacuum or space because it must have a medium through which to travel.
   c. The velocity of sound varies with the medium and the temperature of the medium through which the energy travels (see Table 35.1).
2. *Velocity of Light And Electromagnetic Energy:*
   a. The radiant energy that produces light waves and other electromagnetic waves travels about 186,000 *miles* per second or about 3×10^{10} centimeters per second.
   b. Radiant energy that produces light waves and other electromagnetic waves can travel through a vacuum or space; it does not require a medium through which to travel.
   c. Radiant energy can travel through a variety of media. Its velocity is slightly changed as it travels through different media. However, the change is so small that the velocity of radiant energy is for most purposes considered to be 186,000 miles per second (see Table 35.1).

Frequency. The pupils should discover and report that the term *frequency* is used to designate *the number of waves that are produced in a specific period of time.* Help these pupils to illustrate their report with large diagrams similar to the ones in Figs. 35.2 and 35.4. In the class these same pupils should repeat their experimentations with different wave frequencies in ropes, coiled springs and in water.

The experiments in Chap. 16, Inquiries 11 and

Table 35.1

VELOCITIES (UNIFORM STRAIGHT LINE SPEEDS) THROUGH DIFFERENT KINDS OF MATERIALS

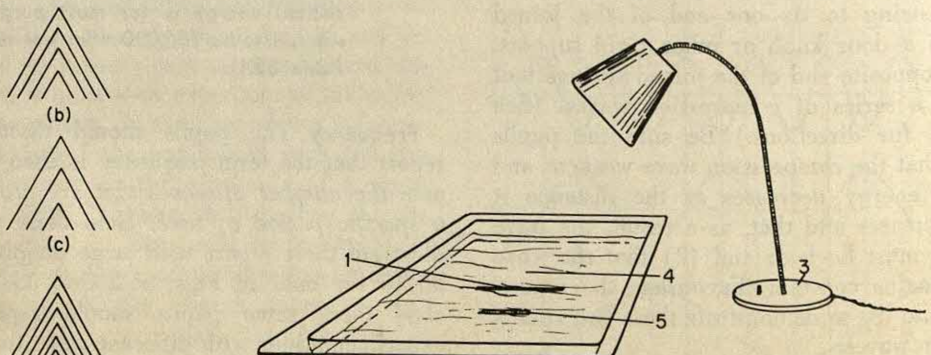
Kind of Energy	Type of Energy	Approximate Velocity (per second)	Medium Traveled Through
Sound	Mechanical (travels only through a medium; cannot travel through vacuum or space)	1,100 feet	Still air (32°F; sea level)
		100 feet	Rubber
		16,000 feet	Iron
		10,000 feet	Ice
		5,000 feet	Water
Electromagnetic	Radiant (travels through vacuum or space or medium)	186,000 miles	Vacuum, space, and air
1. Light		93,000 miles	Diamond
		Slightly less than 186,000 miles	Glass, water, transparent and translucent media
2. Radio		186,000 miles	Air, space
3. Television		186,000 miles	Air, space
4. X-ray		Slightly less than 186,000 miles	Air, space, muscle
5. Ultraviolet		186,000 miles	Air, space
6. Infrared		186,000 miles	Air, space
7. Electric power		Slightly less than 186,000 miles	Air, space, wire

13 could be used to help the children recall that sound waves have different frequencies.

By following the directions in Fig. 35.5, pupils can produce and observe water waves of different frequencies. This experiment *must be done* in a *very dark room.* The lamp should be the only source of light for the experiment.

Substitute a 6-inch ruler for the short pencil

Fig. 35.5 How to make water waves of different frequencies. (a) Set up these materials as illustrated: 1, heavy black line drawn on white paper to represent a fixed mark; 2, white paper placed under a rectangular, clear glass baking dish; 3, table lamp placed at an angle to the surface of the water (this is the only light source used); 4, water covering bottom of dish; 5, short pencil (not submerged). (b) A pattern of a series of water waves, shaped like the point of the pencil, will appear to pass the heavy dark mark when the pencil is rolled back and forth. (c) Pattern of low-frequency waves formed when pencil is rolled slowly. (d) Pattern of high-frequency waves formed when pencil is rolled rapidly. A comparison of (c) and (d) reveals that the wave frequency (number of waves which appear to pass the heavy black line in a given time period) is directly related to the speed with which the pencil is rolled.



used in the experiment shown in Fig. 35.5. In the dish of water, hold the ruler crosswise, with one edge against the bottom of the dish. Move the ruler forward. Lift the ruler out of the water, lower it, and again move it forward. Gradually *increase* the number of times per unit of time (seconds) that the ruler is moved forward and observe the *increase in wave frequency.*

Place the rectangular glass baking dish on the standard of an electric food mixer. Put the white paper, which has the black mark on it, under the dish and arrange a table lamp as shown in Fig. 35.5. Cover the bottom of the dish with water. Insert *one* beater in one of the holders. Position this beater at one end of the dish. Turn the mixer to its *lowest speed.* Observe the waves produced. Gradually increase the speed of the beater. What changes can be observed? (As the beater rotates faster, there is an *increase in wave frequency.* There is also a *decrease in wave length.*)

Wave Length and Frequency. Experiments with pendulums can further clarify the relationship between wave length and frequency. First set up *one* simple pendulum similar to the ones in Fig. 35.6. Observe the back-and-forth or to-and-fro motion of a swinging pendulum. Ask the pupils how they can *show* that this vibratory energy is wave energy. (When the weighted end of the swinging pendulum is allowed to touch water, water waves will be produced. If a swinging pendulum is allowed to touch lightly a paper covered with wet fingerpaint, as the paper is moved at right angles to the direction of the pendulum's swing, a typical wave pattern will be traced in the paint.)

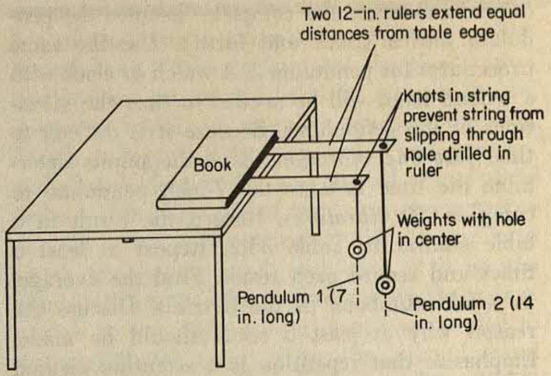

Two 12-in. rulers extend equal distances from table edge
Knots in string prevent string from slipping through hole drilled in ruler
Book
Weights with hole in center
Pendulum 1 (7 in. long)
Pendulum 2 (14 in. long)

Fig. 35.6 An experiment to find the relationship between wave length and frequency (see text).

Finally, have the group demonstrate for the class the *two*-pendulum experiment detailed in Fig. 35.6 and Table 35.2. The experimental procedure is as follows: Raise pendulum 1 by bringing it to the right until it is *level* with the ruler to which it is attached. Check position of the sweep second hand on a watch or clock. Release pendulum and count the *first* 10 forward movements. Record time. Repeat until 6 trials are completed. Then, after the pendulum has completed several swings, use the same proce-

Table 35.2

FREQUENCIES AND WAVE LENGTHS FOR 7- AND 14-INCH PENDULUMS

	Frequency				Wave Length	
	7-inch Pendulum (short)		14-inch Pendulum (long)		7-inch Pendulum (short)	14-inch Pendulum (long)
Trial Number	Number of sec for 10 vibrations	Number of vibrations per second	Number of sec for 10 vibrations	Number of vibrations per second	Length of swing (in inches)	Length of swing (in inches)
1	6		13		3	6
2	5		12		3	6
3	6		10		3	6
4	5		9		3	6
5	5		10		3	6
6	5		10		3	6
Average in whole numbers:	5	2	10	1	3	6

dures to measure the complete distance the pendulum moves (back and forth). Use the same procedures for pendulum 2. A watch or clock with a second hand will be needed to time the vibrations of the pendulums. Because it is difficult to time *just one vibration,* have the pupils determine the time it takes the 7-inch pendulum to complete *10 vibrations.* Record the result in a table similar to Table 35.2. Repeat at least 6 times and record each result. Find the average, in whole numbers, of the 6 trials. Discuss the reason why at least 6 trials should be made. Emphasize that repetition is a scientific method of reducing errors. (Errors in counting, timing, and any variables in the forces acting on the pendulum, when it is set in motion, tend to be averaged out.) If the 7-inch pendulum completed 10 vibrations in 5 seconds, how many vibrations were there in 1 second? (2 vibrations per second.) What was the frequency of the 7-inch pendulum? (2) Repeat the procedures used for the 7-inch pendulum with the 14-inch pendulum. Find the number of seconds needed for the pendulum to complete 10 vibrations. Record and average the results of at least 6 trials. If the 14-inch pendulum completed 10 vibrations in 10 seconds, how many vibrations were there in 1 second? (1 vibration per second.) What was the frequency of the 14-inch pendulum? (1)

After the frequencies of the short and long pendulums have been computed, use a yardstick to measure the pendulums' wave lengths (length of a pendulum's swing). Wave lengths of 3 and 6 inches were recorded each time for the 7- and 14-inch pendulums after they had settled into their rhythmic swing.

Have the entire class help to establish the relationship between each pendulum's frequency and wave length. The 7-inch pendulum had the higher frequency and the shorter wave length. The 14-inch pendulum had the lower frequency and the longer wave length. Waves with short wave lengths have a high frequency and waves of longer wave lengths have a lower frequency.

Wave Lengths, Frequency, and Velocity. Information similar to the following should be discussed and illustrated with experiments and diagrams to help the children develop an understanding of the relationship between wave length, frequency and velocity:

1. Sound wave energy of different frequencies travels at the *same velocity* through the same medium.
   a. Vary the experiments suggested for echoes and echolocation (Chap. 16, Inguiry 14) in order to compare the *time* it takes for echoes from low- and high-pitched sounds (low and high frequencies) to be heard. (The time will be the same for both.)
   b. Blow at one time as many pitch pipe notes as possible. Compare the original sound with the sound of the echo. (The echo will sound weaker, but it will contain the same mixture of sound frequencies.) Why? (Wave energy of different frequencies travels at the same velocity.)
   c. Other examples that can be used as further evidence that sound wave energy of different frequencies travels at the same velocity in the same medium are as follows: The sound wave energy of the many musical notes played together by an orchestra reaches our ears at the same time. Melodies would sound jumbled if they did not. In choral speaking the mixture of low and high frequency voices is heard clearly and distinctly.
2. Light and other electromagnetic wave energy travel at the *same velocity* through the same medium.
   a. Do several of the experiments in Chap. 29, Inquiries 2 and 6, which provide evidence (1) that white light is a mixture of colors (mixture of different wave lengths or different frequencies) and (2) that some colors are combinations of two different colors (different wave lengths or different frequencies).
   b. Other examples that can be used as further evidence that light wave energy of different frequencies travels at the same velocity are: Multicolored paintings are seen as a whole. The many colors of a natural landscape are seen as a unit. The many colors in a sunset are all detected at the same time. When a crowd of people are wearing many different colors, the colors are all seen at the same time. Different colors (different wave lengths or different frequencies) travel at the same velocity.
   c. Examples that can be used as evidence that radio and television wave energy travel at the *same velocity* are: At 9 a.m., for example, you can select any one of the many radio programs being broadcast from stations on different frequencies. You can

also select any one of the many television programs being sent simultaneously from stations broadcasting on different frequencies. When news events, for example, are broadcast simultaneously by radio and television, your radio and television receiving sets will receive them at the same time. The wave frequencies that carry television sound and picture signals are both broadcast and received together. In each illustration, wave energy of different lengths or different frequencies is traveling at the same velocity.

5. What is the mathematical relationship between wave velocity, wave length and wave frequency? Why is this relationship important?

In this experiment the children are asked to build and use a wave pattern model. The use of this model will help them to: (1) see the relationship that exists between velocity, wave length, and frequency, and (2) discover for themselves that this relationship can be expressed as a simple mathematical formula. Have each child make a 12-inch ruler from a piece of cardboard that is 12 inches long and 2 inches wide and rule lines across it dividing it into inches. Assign wave lengths of 1, 2, 3, 4, 6, and 12 inches to the children. Ask them to draw in pencil on their cardboard ruler a wave pattern in which the waves have the wave length assigned to them. When the wave lengths of the finished wave patterns have been checked, have the children trace over them with colored crayons. Ask each child to choose a partner who has a different wave length. Hang an electric clock that has a sweep second hand on the wall where each member of the class can see the movement of the second hand. Make certain that the class knows that it takes the second hand 60 seconds or one minute to make one complete sweep of the dial. Direct each pair of partners to lay two commercially made foot rulers end to end across their desks and to place one of their two wave patterns parallel to the left-hand ruler. Ask the pupils to watch the second hand, and when it is on the number 12 on the dial, to slowly move their wave pattern to the right so that it will be parallel to the right-hand ruler when the second hand reaches the number 12 again (see Fig. 35.7). Repeat the same procedures with the second wave pattern. Ask questions like these: How far did you move the wave pattern? (12 inches.) How far did each crest in your wave pattern move? (12 inches.) How long did it take you to move the wave pattern through this distance? (1 minute.) During the minute the wave pattern was moved, how many wave crests appeared at the junction of the two rulers? (The number drawn on the pattern.) At what *velocity* did the wave patterns and the wave energy in these patterns move? (The velocity will be the same for each pattern. It is 12 inches per minute.)

Now have the children who were assigned to make patterns of waves of the *same length* assemble in groups. Ask one representative from each group to write on the chalkboard the velocity, wave length and frequency of the waves in his group's patterns (see Table 35.3). Let the class examine the figures listed on the chalkboard and determine the mathematical relationship that exists between the velocity, wave length, and frequency of each of the different wave patterns. (The velocity *always* equals the wave length

Fig. 35.7 How to experiment with home-made wave patterns (see text).

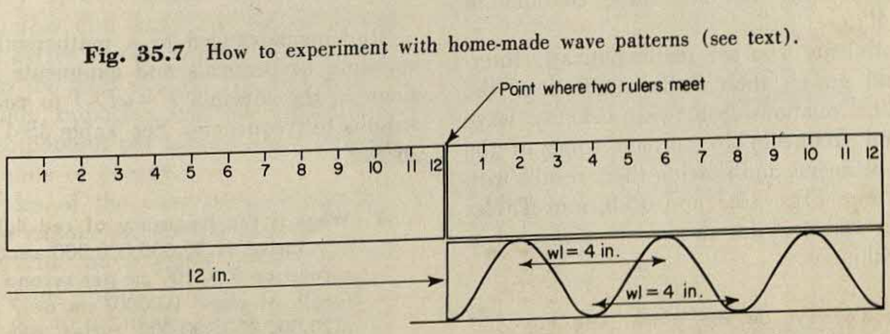

Point where two rulers meet
1
2
3
4
5
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
9
10
11
12
wl = 4 in.
wl = 4 in.
12 in.
Distance through which wave pattern was moved in 1 minute
Position of wave pattern at end of 1 minute

Table 35.3

VELOCITY EQUALS WAVE LENGTH MULTIPLIED BY FREQUENCY ($V = wl \times f$)

Velocity per Minute (inches)	Wave Length	Frequency
12	2	6
12	6	2
12	12	1
12	4	3
12	1	12
12	3	4

multiplied by the wave frequency.) Check the children's understanding of this mathematical relationship by asking them questions like these: If you know the length and frequency of a wave, how can you find its velocity? (Multiplying the length and frequency gives the velocity of a wave.) If you know the velocity and the wave length, how can the frequency be determined? (Dividing the velocity by the wave length gives the wave frequency.) If the velocity and the wave frequency are known, can the wave length be determined? How? (By dividing the velocity by the frequency the wave length can be determined.) How can this mathematical relationship be written? (Velocity = wave length × frequency, or $V = wl \times f$.)

Pupils should learn that waves can be classified *either by their frequency* or *by their wave length* and that, whichever is conventionally used, it is always possible to find the other by applying the formula, $V = wl \times f$. Conventionally a sound wave is listed by its *frequency*. (See Table 16.5 and Fig. 16.7.) Infrared rays, visible light rays, ultraviolet rays, X-rays, gamma rays and cosmic rays are more often listed by their *wave lengths.* (See the last three columns in Table 35.4.)

Those students who are mathematically interested could enrich their understanding of the mathematical relationship between velocity, wave length, and frequency by solving some of the following problems and sharing their results with the class. Use Figs. 16.7 and 16.8, and Tables 16.1, 16.5, and 35.4 for the numbers needed to do the arithmetic.

1. Select 6 keys on the piano. Use Fig. 16.7 to detemine the frequencies of these keys. Convert these frequencies to wave lengths using the velocity of sound traveling through still air at sea level at 32°F (Table 35.1).
2. What is the *wave length* of the lowest and highest piano key on the keyboard shown in Fig. 16.7? Also see Fig. 16.7 for frequencies of these two keys. (Wave length of the lowest key shown in Fig. 16.7 is approximately 41 feet. Wave length of highest key shown is approximately 0.26 feet.)
3. What is the *wave length* of the lowest and highest tone in the human audible range? See Table 16.5 for frequency range of human hearing. (Lowest audible wave length approximately 55 feet; highest, approximately 0.06 feet.)
4. What are the longest and shortest sound waves usually produced by a soprano, tenor, alto and bass voice? See Fig. 16.8 for approximate octave ranges of these voices and Fig. 16.7 for frequencies. (A soprano produces an approximate range of wave lengths from 5 to 1.25 feet; an alto, from 6 to 1.4 feet; a tenor, from 10 to 2.5 feet; and a bass, from 13 to 3 feet.)
5. What are the longest and shortest sound waves produced by a violin, viola, cello, and double bass? See Fig. 16.8 for approximate octave ranges of these instruments and Fig. 16.7 for frequencies. (Violins produce wave lengths from approximately 5 to 0.4 feet; violas, from 8 to 1 foot; cellos, from 17 to 2 feet; double basses, from 20 to 4 feet.)
6. Select one sound frequency in the piano keyboard such as middle C (261 vibrations per second) and determine its approximate wave length as it travels through air, rubber, iron, ice, and water. See Table 35.1 for velocity of sound in these media. (Middle C has an approximate wave length of 4 feet as it travels through *air*; of 0.4 feet as it travels through *rubber*; of 61 feet as it travels through *iron*; of 30 feet as it travels through *ice*; and of 19 feet as it travels through *water*.)

Students advanced to a mathematical understanding of decimals and exponents may apply them in the formula $V = wl \times f$ to convert wave lengths to frequencies. See Table 35.4 for figures to use.

1. What is the frequency of red light which has a velocity of 30,000,000,000 centimeters per second or 3×10^{10} cm per second and a wave length of about 0.00007 cm or 7×10^{-5} cm? (420,000,000,000,000 cycles per second or 4.2×10^{14} cycles per second.)
2. What is the frequency of violet light which

also has a velocity of 30,000,000,000 cm per second or 3 × 10^{10} cm per second and a wave length of about 0.00004 cm or 4 × 10^{-5} cm? (750,000,000,000,000 cycles per second or 7.5 × 10^{14} cycles per second.)

3. **What is the frequency of standard broadcast AM waves which have a velocity of approximately 186,000 miles per second and a wave length of approximately 328 feet? (About 3,000,000 cycles per second.)**

6. How do scientists classify radiant energy? In what ways is all radiant energy alike? How does it differ?

See Table 35.4 for the names of the radiation bands and their frequencies. These bands are arranged in column 3 in the form of a graph called the radiant energy spectrum. It has a dual scale of measurement. The numbers in column 2, to the left of the radiation band graph, are the *frequencies of the radiation* and the numbers in column 4, to the right of the radiation band graph, are the *wave lengths of the radiation.* These numbers are written with exponents, which are sometimes positive and sometimes negative. See, for example, in the parentheses in column 2 how the frequencies 10^4, 10^3, 10^2, and 10^1 are converted to conventional numbers. Having the pupils convert frequencies like 10^{23}, 10^{21}, 10^{18}, and so on, to conventional numbers will dramatically demonstrate *how very high the frequencies are* in the cosmic, gamma, and X-ray bands.

Make certain the pupils understand that the *frequency number* in Table 35.4 designates the number of waves that are produced in one second. (See Inquiry 4.) When they have completed Inquiry 9, they should realize that the *frequency number* also designates the *number of photons* that arrive in one second. Which radiation band has the most energy? (Cosmic band.) Why? (Cosmic radiation has the highest frequency; more photons per second. More photons mean more units of energy.)

For examples of the conversion of numbers with negative exponents, see the conversions in parentheses in the wave length column number 4. By converting wave lengths 10^{-13}, 10^{-11}, 10^{-8}, and so on, to decimals, pupils can dramatically demonstrate how very short these wave lengths are.

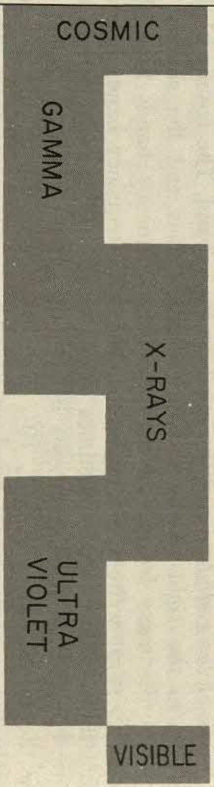
Help the pupils to understand that all radiant energy has the same velocity. (Radiant energy velocity is rounded off to 186,000 miles per second or 3×10^{10} centimeters per second.) Pupils should also realize that different kinds of radiation are only different frequencies or different wave lengths. The radiation band graph should also clearly show pupils that the visible light band is only a very small part of the whole radiant energy spectrum.

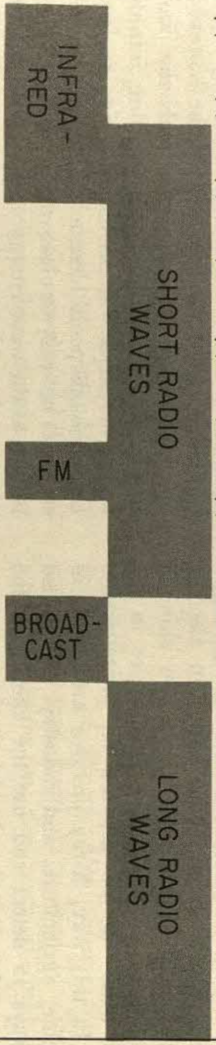
Help the students obtain the following information from Table 35.4. Radio and television frequencies are *lower* than visible light frequencies. Radio and television wave lengths are *longer* than visible light wave lengths. Ultraviolet frequencies are *higher* than visible light frequencies. Ultraviolet wave lengths are *shorter* than visible light wave lengths. The X-ray and gamma bands have frequencies *higher* than the ultraviolet band. The X-ray and gamma bands have *shorter* wave lengths than the ultraviolet band. The cosmic band has the highest frequencies and the shortest wave lengths. High frequency bands have short wave lengths; lower frequency bands have longer wave lengths.

Also, make certain that the pupils summarize the following facts. The eyes are sensitive receivers of only a very small part of the radiant energy spectrum. This band, called the visible light band, represents a comparatively *small frequency range*. The frequency range of visible light varies from the frequency of red light to the frequency of violet light. (Red light, 420,000,000,000,000 cycles per second to violet light, 750,000,000,000,000 cycles per second.) The wave length of visible light varies from the wave length of red light to the wave length of violet light. (Red light, 0.00007 cm to violet light, 0.00004 cm or from 7000 angstroms for red light to 4000 angstroms for violet light.) See columns 4, 5, and 6 of Table 35.4 for the size of *one angstrom unit.* (One angstrom equals 10^{-8} *centimeters* or one ten-millionth of a *millimeter.*) One angstrom unit of measurement is in the order of magnitude of the diameter of an atom. Show the class a meter stick and explain that each of the 100 parts into which it is divided is one centimeter and that each of the 10 parts of one centimeter is one millimeter. The length of one millimeter can be seen. Now ask the class to imagine this one millimeter divided into 10 million parts. The size of each one of these 10

Table 35.4
RADIANT ENERGY SPECTRUM

Velocity is 3×10^{10} cm/sec or 186,400 mi/sec. Frequency multiplied by wave length equals velocity: $f \times wl = v$
$f \times wl = 3 \times 10^{10}$ or $f \times wl = 186{,}400$

Information	Frequency (cycles per sec)	Radiation Band	Wave Length in Centimeters	Wave Length by Name	Wave Length (Descriptive size)
Cosmic rays: used to study subatomic particles	10^{23}		10^{-13}		Trillionth of a millimeter (mm)
	10^{22}		10^{-12}		Hundred billionth of a mm
Gamma rays: used for cancer treatment	10^{21}		10^{-11}		Ten billionth of a mm
	10^{20}		10^{-10}		Billionth of a mm
X-rays: used in medicine, agriculture, and industry	10^{19}		10^{-9}		Hundred millionth of a mm
	10^{18}		10^{-8}	*Angstrom**	Ten millionth of a mm
	10^{17}		10^{-7}	(10 angstroms)	Millionth of a mm
Ultraviolet rays: cause sun tan; produce vitamin D in people and plants; kill germs	10^{16}		10^{-6}	(100 angstroms)	Hundred thousandth of a mm
	10^{15}		10^{-5}	(1000 angstroms)	Ten thousandth of a mm
Visible light: causes vision and photosynthesis	10^{14}		10^{-4}	Between 4000 and 7700 angstroms	Thousandth of a mm



Infrared rays: produce heat	10^{13}	10^{-3} (0.001)	Micron	Hundredth of a mm
	10^{12}	10^{-2} (0.01)		Tenth of a mm
Microwaves: (shortest radio waves) used by radar, and to relay TV signals across country	10^{11}	10^{-1} (0.1)	Millimeter	0.03937 inches
	10^{10}	10^{0} (1)	Centimeter	0.3937 inches
	10^{9}	10^{1} (10)		3.937 inches
	10^{8}	10^{2}	Meter	39.37 inches
TV and FM radio: eliminates static; amateur radio; television *sound* is FM	10^{7}	10^{3}		32.8 feet
Short radio waves: used by police, firemen, armed forces, ships at sea				
Standard broadcast: AM from 550,000 to 1,600,000 cycles or 550 to 1600 kilocycles	10^{6}	10^{4}		328 feet
	10^{5}	10^{5}	Kilometer	0.6214 miles
Long radio waves: used by airplanes and submarines	10^{4} (10000)	10^{6}		6.214 miles
	10^{3} (1000)	10^{7}		62.14 miles
	10^{2} (100)	10^{8}		621.4 miles
Electric power	10^{1} (10)	10^{9}		6214 miles

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* Comparable to diameter of an atom.

million parts would be the size of one angstrom. If the pupils can imagine 7000 of these angstrom units, they have imagined the wave length of red light. Imagine 4000 of these angstrom units for the wave length of violet light. Wave lengths longer than 7000 angstroms and shorter than 4000 angstroms cannot be sensed by human eyes.

The lower frequencies (longer wave lengths) of the infrared band of radiant energy can be sensed because they cause us to feel warm. Borrow an infrared lamp and observe that the frequencies and wave lengths from it cause your hand to feel warm. (Most inexpensive infrared lamps also give off some frequencies and wave lengths of visible red light. It is these which you see.) The still lower frequencies of the television and various radio bands in the radiant energy spectrum can be detected by television and radio antennas.

Ultraviolet frequencies with wave lengths shorter than those of violet light can also be detected. Ultraviolet light causes the skin to change color (suntan). The frequencies in the X-ray band can be detected on photographic film. In this way, X-ray pictures are useful in medicine, agriculture, and industry. There also are ways to detect and use the energy in the gamma and cosmic bands of radiation.

7. How many wave characteristics of radiant energy can be demonstrated in differently shaped swimming pools?

This inquiry provides opportunities to apply the understandings of wave characteristics that have been developed in Chap. 32 through 34 and in Inquiry 1 of this chapter.

Investigate the possibilities for taking a trip to observe wave action in well-lighted swimming pools. The pools selected for these observations should be lighted by either sunlight or overhead fluorescent light, and the pools should also have walls that will act as plane, concave, and convex reflectors. A pool that is rectangular and another that has a free form or kidney shape will provide the three different shapes of reflecting surfaces needed for this study of wave action.

Appoint a committee to visit the pools selected. Ask this committee: (1) to obtain the owner's permission to use the pool; (2) to find out whether the owner will be willing to turn off the water circulator while the class conducts experiments; (3) either to measure or to obtain from the owner the approximate dimensions of the pool; and (4) if the pool is outdoors, to learn the best time of day to see the wave patterns on the bottom of the pool. (Outdoor pools that are surrounded by shrubbery, trees, and buildings should be visited when these objects will not cast their shadows on the bottom of the pool, thus interfering with the observation of wave patterns.)

After the committee has made its report to the class, discuss the kinds of objects that can be used as wave makers, refracting, and diffracting surfaces. A small spade, a dowel rod or pipe, which is at least 12 inches long and 1 inch in diameter, and a watering can with a long spout are good *wave makers*. Also, plan to take a rope that is long enough to reach across the length of the pool so the class can see the change in the *amplitude* of the wave pattern on the bottom of the pool as the wave energy travels the pool's length. If the pool has steps leading into the water, the steps will act as *refracting* surfaces. Even though pools have a shallow and a deep end, it is not easy to observe the changes in wave lengths as the wave energy moves from one depth to the other because the change in depth is usually very gradual. For this reason, it may be necessary to use pool steps or something like a *plastic cold box* to observe the change in wave length that is caused by two different depths of water. The cold box can be filled with water at the pool, and the lid can be securely tied on to it. When the cold box is submerged in the shallow end of the pool, it will provide the abrupt change in water depth required to observe the change in wave length caused by refraction. Toy boats or wedge-shaped wooden floats make good *diffracting* devices.

The following characteristics of wave action can be observed at the pool: (1) the disturbance that produces water waves; (2) the wave formations as the disturbance travels across the pool; (3) the decrease in the amplitude of the waves as the wave energy is expended; (4) the changes in the shape of the waves that are reflected from plane, concave, and convex surfaces; (5) the changes in the shape and length of the waves caused by refraction; (6) the diffraction of waves caused by the wave disturbance as it passes around the thin edges of object; and (7) the interference effects caused by the blocking and reinforcement of one wave by another wave. Methods for demonstrating each of these wave characteristics are described and the observations that the children can make are discussed in the following paragraphs.

1. Wave Disturbance. Use either a child's snow shovel or a small spade for a wave maker. Hold the tool by the handle and push the opposite end slowly forward in the water. Look on the bottom of the pool for the shadow of the disturbance produced by the spade. This shadow pattern of the disturbance will look like water that is boiling vigorously. A *wave pattern* shadow will form around the disturbance and will *appear to move* outward from it (see Fig. 35.8).

2. Patterns of Wave Formations as the Disturbance Travels from One End of the Pool to the Other. At the deep end of the pool, have a child stand about two feet back from the edge of the pool, and at the shallow end, have a second child stand the same distance back from the pool's edge. Give each child one end of a long rope and have them stretch the rope between them *above* the surface of the water. Near the rope at one end of the pool, use the tool from the previous experiment to produce a wave disturbance that travels parallel to the rope. As the wave disturbance travels to the other end of the pool, its progress can be observed by watching the undulations in the rope's shadow on the bottom of the pool (see Fig. 35.9).

3. The Decrease in the Amplitude of the Waves as the Wave Energy is Expended. Use the tool again to watch the decrease in the intensity of the wave pattern as the disturbance moves away from the wave maker.

Pour some water from the long spout of the watering can into the pool. Again observe that with distance the wave pattern becomes weaker and weaker and that finally the pattern can no longer be detected.

Repeat the experiment with the rope several times and observe the decrease in the motion of the rope's shadow as a wave disturbance travels the length of the rope. The undulations in the pattern become weaker and weaker as the energy is expended.

4. The Changes in the Shape of Waves That Are Reflected from Plane, Concave, and Convex Surfaces. Observe the wave patterns that are reflected from the plane, convex, and concave inner walls of a pool. Also observe the wave patterns change from wavy lines to diamond-shaped patterns as the wave disturbance is

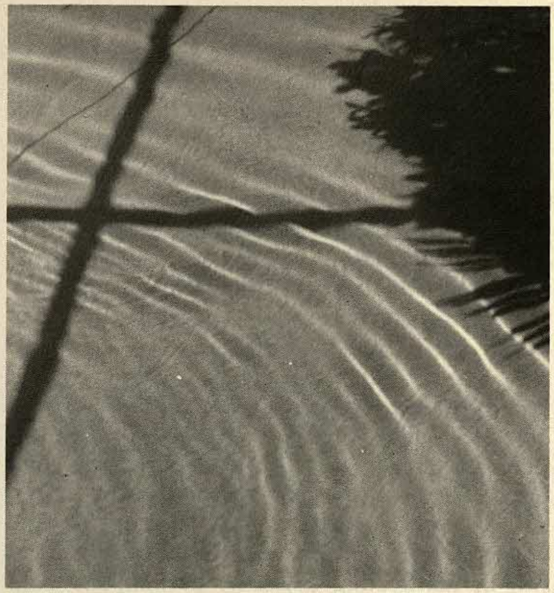
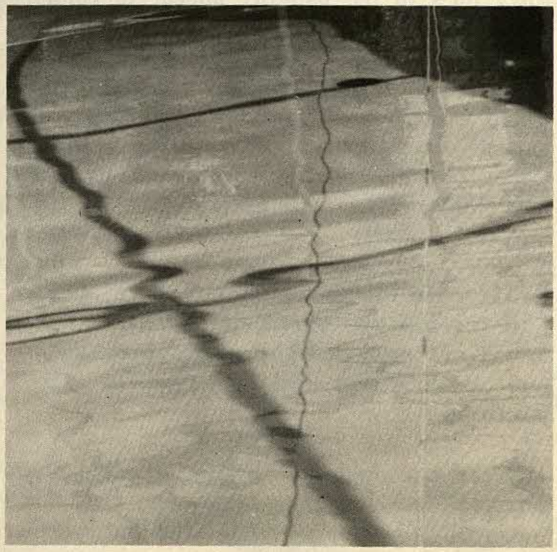


Fig. 35.8 A wave pattern seems to move across the pool.

Fig. 35.9 A wave disturbance traveling across the pool causes a wave pattern in the black shadow of the white rope, and in the shadow of the pool's overhead frame.



reflected back and forth from one side of the pool to another.

5. The Changes in the Shape and Wave Length Caused by Refraction. If the shallow end of the pool has steps, observe the refraction pattern that forms as the water waves *appear to travel* over the steps. A similar observation can be made with an old box if pool steps are lacking.

Help the class to clarify their concepts of *refraction* (see Chap. 33). Sharp bending, distortion in wave pattern, and changes in the wave length are caused by refraction.

6. The Diffraction of Waves Caused by the Wave Disturbance Passing Around the Thin Edges of Objects. Tie a string to a toy boat or a wedge-shaped piece of wood. Push the object out into the water to a place where a shadow of the object can be seen on the bottom of the pool. Make a wave disturbance move toward the broad side of the floating object by pushing the wave maker forward through the surface of the water. Watch the gentle curving of the wave pattern around the shadow of the thin edge of the wedge-shaped toy.

Help the class to clarify their concepts of *diffraction* (see Chap. 33). Both light waves and water waves are gently bent (diffracted) around thin edges of objects.

7. Interference Effects Caused by the Blocking and Reinforcement of Waves. Push the wave maker forward vigorously in the water and observe the interference effects adjacent to the disturbance. Note that some of the crests (white wavy lines in the pattern) appear to combine into one crest and some of the troughs appear to combine into one trough (reinforce each other). Also watch for places in the wave pattern in which a crest *blocks* a trough and causes this part of the wave pattern to disappear. Dribble water from the watering can into the pool and note similar interference effects.

8. How do electromagnetic wave energy and mechanical wave energy differ? What are some of the characteristics that both waves and particles have in common?

In the preceding inquiries, the wavelike effects common to electromagnetic and mechanical waves have been developed. Find out whether the students can name the two conditions that *must exist* for the formation of such mechanical waves as water and sound. [(1) There must be a wave generator or a source of wave energy. (2) There *must be a medium* that will vibrate as the wave energy travels through it.] Recall the experiences in Chap. 16, Inquiry 5 in which the concept was developed that sound waves *will not travel through a vacuum.* Also, discuss the experiences in Inquiries 1 through 6 in which the class learned that mechanical wave energy travels through a medium by forming a succession of wave disturbances. Encourage the pupils to deduce why a wave theory cannot be used to explain how radiant energy travels through *space.* (There is not enough matter in space to produce a succession of waves.)

Use textbooks and reference books to find information about the medium (ether) *that was assumed to exist* when the wave theory was used to explain *every behavior of radiant energy.* There is no evidence that "ether" or any other medium that is sufficiently dense to produce a succession of waves exists in space. For this reason, the wave theory cannot be used to explain how radiant energy travels from the sun to the earth. Since radiant energy does travel through space, it is reasonable to assume that it is composed of energy particles.

Mass or matter can travel through both space and a vacuum. What evidence is there to support the theory that radiant energy is composed of *tiny particles of matter in motion?* Read in Chap. 41, Inquiry 3 about the discovery of the *Edison Effect.* This was the first evidence that could be used to support the Quantum (Photon) theory. (The escape of particles—electrons—from a hot—radiant—metallic filament in an electric bulb or a vacuum tube is called the Edison Effect.) The application of this discovery led to the invention of vacuum tubes which have made radio, radar, television, and other telemetry devices possible (see Table 35.5).

The formation of shadows can be more easily explained by the theory that radiant energy is composed of tiny oscillating particles. Opaque objects block the light that strikes them. If the light had *only* the characteristics of waves, no sharp shadows would be formed. The waves would be diffracted around the edges of the objects. These edges would also reduce the velocity of the waves and cause further distor-

Table 35.5

SUPPORTING EVIDENCE THAT RADIANT ENERGY IS COMPOSED OF PARTICLES THAT HAVE WAVELIKE CHARACTERISTICS

Evidence for Particlelike Behavior	Evidence for Wavelike Behavior
1. Particles can travel through space.	1. Wave energy travels outward in all directions from its source.
2. Camera images are less bright than the camera subject because not all particles reflected from the subject succeed in passing through the small lens opening in the camera.	2. Camera images are inverted because at the small lens opening in the camera waves can cross each other undisturbed.
3. Particles can be reflected.	3. Waves can be reflected.
4. Particles can be refracted.	4. Waves can be refracted.
5. Particles can be *blocked* but not reinforced. Sharp shadows seem to form because particles are blocked.	5. Waves can be *both blocked and reinforced.* Interference effects (the blocking and reinforcing of waves) on the edges of objects are caused by the diffraction (bending) of waves around the object.

tions in the shadow effects. The formation of sharp shadows seems to be further evidence to support the theory that radiant energy is composed of tiny vibrating particles.

Marbles can be used to help the children visualize that *particles* (*photons*) have some *characteristics* that are common to waves. Let them think of ways to use marbles to show that particles as well as waves can be reflected and refracted. Figures 35.10 and 35.11 suggest some experiments that can be done to observe reflection from plane (smooth and rough), concave, and convex surfaces.

Assemble either wallboard or a bread board as shown in Fig. 35.10. Use a marble to represent a particle of radiant energy. Tape cardboard folded into a V shape to the end of a 6-inch ruler to shove the marble along the dotted diagonal

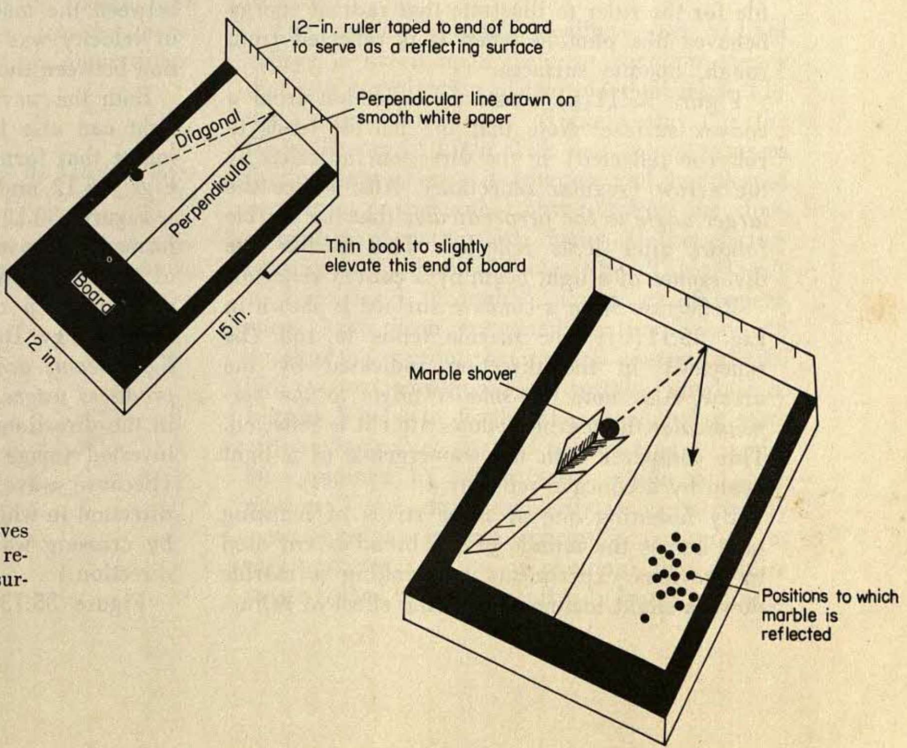

12-in. ruler taped to end of board to serve as a reflecting surface
Perpendicular line drawn on smooth white paper
Diagonal
Perpendicular
Thin book to slightly elevate this end of board
Board
12 in.
15 in.
Marble shover
Positions to which marble is reflected

Fig. 35.10 Radiant energy behaves like particles (photons) when it is reflected from smooth, plane, opaque surfaces.

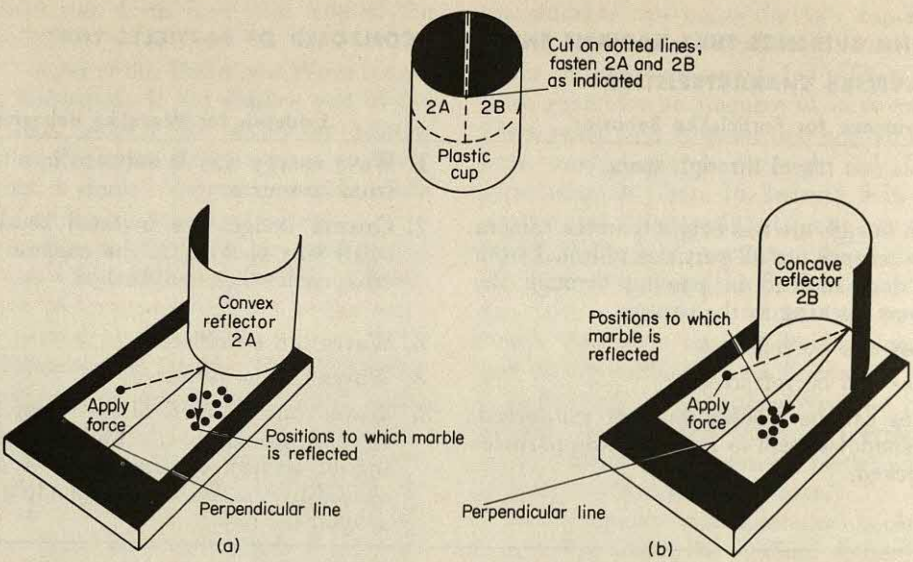


Fig. 35.11 Radiant energy behaves like particles (photons) when it is reflected from convex and concave opaque surfaces.

line until it strikes the reflective surface being tested. Draw small dots to the *right of the perpendicular line* to mark the position in which the marble is reflected. Observe reflection from a *smooth plane surface* (the 12-in. ruler). Observe that the marble tends to roll (be reflected) in the direction indicated by the arrow (regular reflection). Substitute a scrub brush or a wooden file for the ruler to illustrate that radiant energy behaves like photons when it is reflected from rough, opaque surfaces.

Figure 35.11(a) illustrates reflection from a convex surface. Note that the marble tends to roll (be reflected) in the direction indicated by the arrow (regular reflection). Also notice the *larger angle to the perpendicular* that the marble follows after it is reflected. This is like the divergence of a light beam by a convex reflector.

Reflection from a concave surface is shown in Fig. 35.11(b). The marble tends to roll (be reflected) in the direction indicated by the arrow. Also note the *smaller angle to the perpendicular* the marble follows after it is reflected. This compares with the convergence of a light beam by a concave reflector.

By fastening one or more strips of masking tape across the middle of the bread board used in previous experiments and rolling a marble down a slight incline over it, the effect of *refraction caused by a decrease in velocity* can be observed. Cover this same board with a piece of cloth that has a rough texture and paste a *smooth* (glazed) strip of paper across the center of the cloth. Roll the marble down the incline and observe the *refraction caused by an increase in the velocity* of the marble. (The decrease in velocity was caused by the increase in friction between the marble and the tape. The increase in velocity was caused by the decrease in friction between the marble and the smooth paper.)

Both the wave and particle characteristics of light can also be used to explain the inverted image that forms on the film in a camera (see Figs. 35.12 and 35.13).

Figure 35.12 illustrates an inverted image formed by wave energy. Draw a large diagram of this illustration on white paper and use the diagram in a discussion of images formed by *wave energy*. During this discussion *assume that light beams are composed only of energy that produces waves*. Will the wave energy traveling in the directions shown in the diagram form an inverted image on the film? (It will.) Why? (Because wave energy continues in the same direction in which it is moving. It is undisturbed by crossing wave energy moving in a different direction.)

Figure 35.13 shows how an inverted image

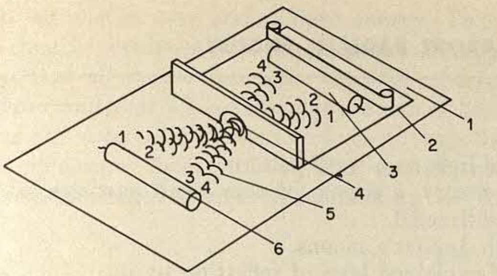
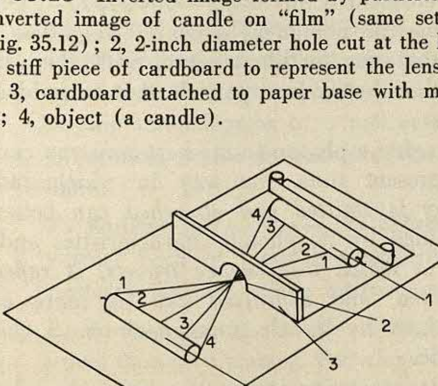


Fig. 35.12 Inverted image formed by wave energy. Key: 1, large piece of white paper; 2, represents film in camera; 3, inverted image of candle on "film"; 4, represents lens opening in camera; 5, wave fronts 1–4 represent the directions followed by wave energy from the candle through the lens opening to the image on the film; 6, object (a candle).

can be formed by particles. Use a marble to represent a particle or photon of radiant energy. Make a marble pusher like the one in Fig. 35.11 and push the marble along line 1 until it enters the hole in the cardboard. Observe that the marble continues to roll in a straight line. Follow the same procedure for lines 2, 3, and 4. In each case the marble continues to roll in a *straight line.* Because particles (represented by marbles) travel in straight lines, *the image* formed on the film *will be inverted.*

The particle or photon theory also explains why the reflected light from the inverted image in a pinhole camera is so much less intense than the light from the object that produces the image. Have the pupils roll a marble from many different angles toward the hole in the cardboard. (See Fig. 35.13.) Keep a record of the number of times the marble is rolled and the number of times the marble passes through the hole. Let the pupils deduce, from the results of this experiment, the reason why the brightness of the image formed on the screen in a pinhole camera is *less intense* than the brightness of the object that produces it. (The pinhole *blocks* many of the photons traveling from the object. *Fewer photons* reach and are recorded on the film. The intensity of light depends upon the number of photons that are reflected from the screen.)

Fig. 35.13 Inverted image formed by particles. Key: 1, inverted image of candle on "film" (same set-up as in Fig. 35.12); 2, 2-inch diameter hole cut at the bottom of a stiff piece of cardboard to represent the lens opening; 3, cardboard attached to paper base with masking tape; 4, object (a candle).



9. Who are some of the great scientists who have advanced theories about the nature of radiant energy and how it travels? What was the contribution of each of these scientists? Which theory is currently acceptable?

The attempt to understand the nature of radiant energy and how it travels has occupied the efforts of many great scientists. See Table 35.6 for the names of some of these scientists and brief information about their contributions. Reports that the pupils make on their reference readings about these scientists should help the class to understand why the theories have been proposed, discarded, changed, combined, and extended.

The modern physics dealing with radiant energy is based upon the *new quantum theory* that is a combination of two older theories: (1) the Corpuscular Theory of Light and (2) the Wave Theory of Light. This *new theory* assumes that radiant energy is composed of bundles of oscillating particles that have some of the characteristics of matter and many of the characteristics of mechanical waves. (See Table 35.6.) In Inquiries 1 through 6, a number of experiences have been suggested that will help to develop the concept that radiant energy behaves like water waves under certain conditions. Inquiry 8 helps to develop the concepts that *some* of the *observable effects* of radiant energy cannot be explained by either wave action or wave motion. These effects can only be explained by assuming that radiant energy is composed of tiny particles (quanta or photons) that acquire mass when they are emitted from luminous

Table 35.6
KEY SCIENTISTS WHO HELPED TO FORM THEORIES ABOUT RADIANT ENERGY

1600–1700 Early Observations

Francesco Grimaldi (c. 1650) noted diffraction of light.
Robert Hooke (before 1665) interpreted diffraction of light as a wave pattern.
Sir Isaac Newton (c. 1669) advanced the corpuscle theory, a stream of very small particles, which he said could be reflected and refracted but not diffracted.
Claus Roemer (1676) established velocity of light with Jupiter's moons.
Christian Huygens (1677) advanced wave theory and explained laws of reflection by it.

1700–1800 Corpuscle Theory (light as particles)

Newton's corpuscle theory was generally accepted through this period. The work of Grimaldi, Hooke, and Huygens waited until the wave theory gained wide acceptance in the 1800's.

1800–1900 Wave Theory (light as waves)

Thomas Young (1801), *Augustus Fresnel* (1805) noted that the interference effects in diffraction of light waves caused darkness (polarization).
James Maxwell (1860) predicted *electromagnetic wave theory* of light.
Léon Foucault (1862) proved velocity of light was less in a media than in a vacuum.
Heinrich Hertz (1888) produced electromagnetic radio waves and proved they had the main properties of visible light.

1900— Quantum Theory (light as both particles and waves)

Max Planck (1900) postulated that the energy in a light beam was concentrated in small packets (quanta) instead of being spread evenly through the electromagnetic wave.
Albert Michelson (1902) used mirrors to establish velocity of light.
Albert Einstein (1902) strengthened Planck's quantum theory. Name *photon* was given to the packets of energy with wave characteristics. This new dual nature of light, the quantum theory, explained some things (graininess of light and photoelectric effect) which the wave theory alone could not do. A photon's energy is proportional to its frequency. Intensity is closeness of photons on wave front.
A. H. Compton (1921) found that a photon and an electron in collision behaved the same as two particles in collision.
G. P. Thompson (1925) found electrons (particles) can be made to act as waves.
Davisson and Germes (1925) used Thompson's findings to build electron microscope.

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bodies and cease to exist when their energy of motion is expended. For example, every time an electric light bulb is illuminated, photons stream out from the filament in the bulb. Their energy of motion is gradually transferred to the matter they encounter. *When their energy is expended the photons disappear.* When the lamp bulb is turned off, no more photons are released and no photons exist in the filament in the lamp. The quantum theory is accepted at the present time by scientists as the best explanation of the behavior of radiant energy. Scientists have not yet agreed upon one model (visual concept) for a photon. Some imagine it as a bundle of waves and represent it this way: . Others imagine the photon as a nearly weightless particle that vibrates like a wave. Still others think that the photon is a particle that is guided by waves.

Imagine a photon in the best way you can. At the present time, the way in which radiant energy is *emitted and absorbed* can better be explained by its photon characteristics and *the way in which this energy travels, is reflected, refracted,* and *diffracted* can be more easily explained by its electromagnetic wave characteristics.

It is interesting to speculate upon the relationship between matter and radiant energy. There is scientific evidence that supports the assumptions that *all matter has some wavelike characteristics* and that *all electromagnetic waves have some characteristics of matter.* Even though the new quantum theory of radiant energy has greatly increased man's understanding of its behavior and his ability to control it, much knowledge remains to be discovered.

See Chapter Summary of Process Skills on the front endpapers of this book for process skills that can be practiced while developing the inquiries in this chapter.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. A wave pattern is made by an up-and-down, back-and-forth, or to-and-fro motion. Wave energy is vibratory energy and can travel from one point to another. Wave energy caused the rope, water, rubber tubing, coiled spring, and so on, to visibly vibrate either up-and-down, to-and-fro, or back-and-forth. A wave is the disturbance produced by wave energy. Some waves are visible. Others are invisible.

2. All waves, whether they vibrate up and down or back and forth and whether they are visible or invisible, can be represented by a wavy line (a wave model). The peak or top of a wave is called a crest. The depression between two wave crests is called a trough.

3–4. Waves *seem* to have two common factors—"size" and "speed." Velocity, frequency, and wave length are characteristics that are common to all wave energy. Each of these characteristics can be measured. Long wave lengths have lower frequencies than short wave lengths. Sound wave energy of different frequencies travels at the same velocity in the same medium. Electromagnetic wave energy of different frequencies travels at the same velocity in the same medium.

5. The velocity of a wave is equal to its length multiplied by its frequency. The mathematical formula expressing this is $V = wl \times f$. When one characteristic is unknown, it can be found by applying the formula.

6. Waves produced by radiant energy are alike in that they have frequency, length, and a common velocity. The different kinds of radiant energy differ in their frequency and wave length *but not* in their velocity. The different bands of radiant energy are classified in a graph (based on their frequency and wave length) called the radiant energy spectrum. Visible light wave lengths are so short that they are measured in angstrom units. One angstrom unit is equivalent to one ten-millionths of a millimeter. Different color sensations are caused by differences in the frequencies (vibrations per second) and wave lengths of visible light.

7. Radiant energy waves are believed to have the same characteristics as water waves. Each of these characteristics can be observed by studying the wave patterns formed on the bottom and sides of a well-lighted swimming pool.

8. Radiant energy travels through a vacuum. Sound and water waves cannot travel through a vacuum. Particles do not require a medium through which to travel. The particle characteristic of light better explains the formation of shadows.

Either sunlight or artificial light that strikes an object at an angle forms a sharp shadow of that object. A wave theory cannot fully explain shadow effects, because waves are diffracted around the edges of opaque objects.

Radiant energy has characteristics that are common to *both waves and particles.* Waves and particles can be *reflected and refracted.* Wave energy can also be blocked and reinforced. *Diffraction of wave energy* seems to be the only way to explain both of these effects. Particles of energy can be blocked *but they cannot be reinforced.* For this reason both of the aspects of diffraction cannot be explained by a particle theory.

9. Many scientists have helped to advance our knowledge of light and other wave frequencies in the electromagnetic spectrum. The new quantum theory, which is currently accepted, describes radiant energy as having some of the characteristics of particles (quanta or photons) and all of the characteristics of electromagnetic waves.

Chapter Thirty-Six

Producing Electrical Energy

INQUIRIES

1. In what direction does the electricity produced by a dry cell flow through a circuit? What causes a dry cell to produce a current of electricity?

2. How can chemical cells be made to produce stronger currents of electricity?

3. What are some of the methods that are used to produce current electricity?

4. What is a Leyden jar? How is it charged? Why is a Leyden jar called a condenser or capacitor?

1. In what direction does the electricity produced by a dry cell flow through a circuit? What causes a dry cell to produce a current of electricity?

Divide the class into small groups and have each group wire a simple electrical circuit. (See Chap. 19.) Have each group draw a large diagram of the circuit which they have wired. Also have them use arrows to show the direction in which they think electricity flows through the circuit. Prepare a cutaway cell like the one in Fig. 36.1, and draw a large diagram of it. Discuss the composition of the dry cell and locate

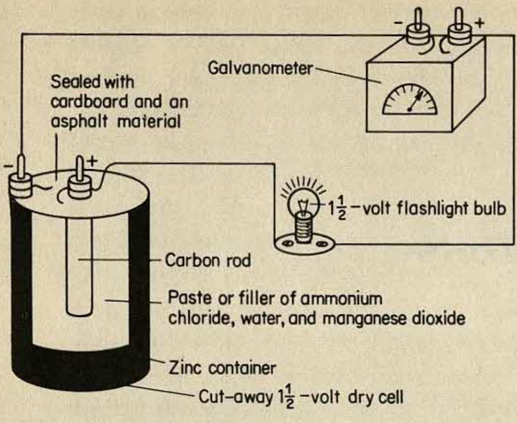

-
+
Galvanometer
Sealed with cardboard and an asphalt material
-
+
1½-volt flashlight bulb
Carbon rod
Paste or filler of ammonium chloride, water, and manganese dioxide
Zinc container
Cut-away 1½-volt dry cell

Fig. 36.1 How to test a worn-out, cutaway dry cell to learn whether or not a small current flows through the circuit.

each of its parts. Develop the concept that electricity is believed to be the movement of electrons in a closed circuit. Discuss what causes the movement of electrons in a circuit. (An electromotive force, or pressure, called *voltage*.)

Also discuss questions similar to this one. What causes the voltage in a dry cell? (An unequal pressure produced by the chemical reaction between the zinc and the ammonium chloride. As the zinc atoms dissolve in the ammonium chloride solution, *they release electrons* which collect on the zinc electrode. This causes *the zinc electrode* to become *negatively charged*. This surplus of electrons produces a repulsive force (like charges repel) or pressure which causes the electrons to move through the wire conductors to the positively charged *carbon electrode*. Because the carbon rod does not have a surplus of electrons, it is positively charged.

Plan and perform experiments to reenforce the concept that the chemical activity between the zinc electrode and the ammonium chloride solution causes the dry cell *to generate* a current of electricity.

Wire the cutaway cell in a circuit containing a 1½-volt flashlight bulb. Encourage the pupils to make predictions regarding what will happen to the light bulb. Will it or will it not light?

Check the accuracy of their predictions with experiments like these: Submerge three-fourths of the cutaway cell in a concentrated solution of table salt and water. Connect the cutaway cell in a circuit as shown in Fig. 36.1. Results? Draw inferences regarding the reasons for the results.

If the bulb does not light, remove the light bulb and socket from the circuit and connect the two ends of the wire to a galvanometer. Does a small current flow through the circuit? (It does.)

Pour out the salt solution and rinse the container in running water. Substitute a solution of water and hydrochloric acid (HCl). Hydrochloric acid is also called muriatic acid. Use one part of concentrated acid to 9 parts of water. Before mixing the acid solution, *discuss the precautions that should be taken when handling acids and mixing acid solutions.*

PRECAUTIONS FOR HANDLING ACIDS AND PREPARING ACID SOLUTIONS

1. **Remove the stopper from the acid bottle and hold it upright between two fingers of the hand that will hold the bottle.**
2. **The acid should be poured very slowly into the *desired amount of water. Never pour water into acid.***
3. **Always pour acids from the side of the bottle opposite from the label.**
4. **Wipe the lip of the bottle against the inside edge of the container into which the acid was poured.**
5. **Replace the stopper on the bottle and *wash your hands.***

Place the cutaway cell in the solution of 9 parts water and one part hydrochloric acid. Make certain that the terminals of the cell extend above the level of the solution. Connect the cell in a circuit with a 1½-volt flashlight bulb. The lamp will glow brightly. Why does the acid solution produce a stronger current than the salt solution?

Use these experiments to check the pupils' answers to the last question. If zinc metal is available, select two pieces which are identical in weight. If it is not available, two pieces can be cut from another "worn out" dry cell.

Pour a measured amount of concentrated salt solution into a small glass container. Pour the same amount of acid solution into a *second glass container* of the same size. Label them. Place a piece of zinc in each of the solutions. Results? (There is a stronger reaction between the acid and the zinc than there is between the salt water and the zinc.)

Set the glass containers aside for several days and then observe the changes that have occurred.

(More tiny zinc particles will be seen in the acid solution than in the salt solution.) Compare the results of these observations with the results obtained in earlier experiments. Why does the acid produce a stronger electrical current? (It releases more electrons and increases the electromotive force, or voltage.)

2. How can chemical cells be made to produce stronger currents of electricity?

Continue to build the concepts: (1) that an excess of electrons on the negative electrode produces an electrical pressure that causes a current to flow through an electrical circuit; and (2) that two metals which react at different rates to chemical solutions can be used to produce an electrical pressure. Also, begin the development of the concept that stronger currents of electricity are produced by increasing the number of excess electrons on the negative electrode. This increase of pressure or voltage can be produced: (1) by moving the two electrodes closer together; (2) by using stronger solutions to produce stronger reactions on metals; (3) by using larger electrodes; and (4) by using both larger electrodes and more of them. The following experiences with several different kinds of simple chemical cells can be used by students to discover these facts.

Cut a strip of zinc and a strip of copper $\frac{3}{4}$ of an inch wide and $2\frac{1}{2}$ inches long. Insert each of the metal strips into a lemon. Connect the metal strips to a galvanometer. How can a current of electricity be detected? (The galvanometer needle is deflected if there is a current.) Experiment to find out whether the *distance between* the metal strips (electrodes) affects the *amount* of current. (The galvanometer needle is deflected more when the electrodes in the lemon are closer together.) Vary the *depth* to which the electrodes are inserted into the lemon. (The current increases when more of the surface of the electrodes contact the acid in the lemon.)

Connect zinc and copper electrodes in a circuit with a galvanometer as shown in Fig. 36.2. Follow these directions: Cut a piece of wallboard about 2 inches wide and long enough to extend over the edges of a glass container. Drill 4 holes in the board through which wire conductors can be attached to electrodes. Cut 2 strips of copper and 2 strips of zinc that are 2 inches wide and long enough to extend from the top to the bottom of the container. Drill or punch a hole near one end of each piece of metal. Insert one end of a wire conductor through each hole in the metal strips and attach as shown. Fill the container $\frac{1}{4}$ full with the first solution to be tested. Place zinc and copper electrodes under holes 1 and 4 and connect to the galvanometer. Record deflection of the galvanometer needle. Move the electrodes closer together. What change occurs? (The galvanometer indicates that a stronger current is flowing in the circuit.) Before testing each new solution, remove and thoroughly wash the electrodes. Also remove test solution and thoroughly wash container before using a new solution.

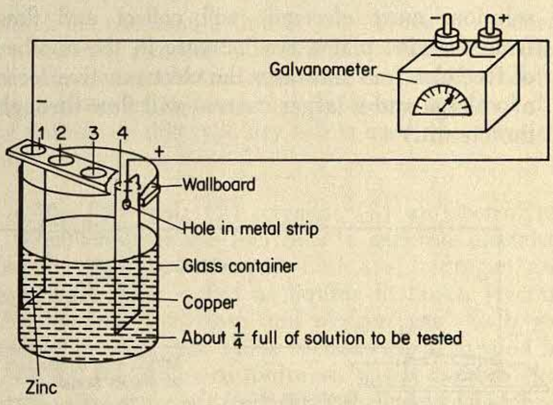


Fig. 36.2 A simple chemical cell.

Compare the amounts of current produced (1) when the distance between the zinc and copper electrodes differs, and (2) when different solutions are used—vinegar and water (half and half), salt and water (concentrated) and hydrochloric acid and water (one part acid to nine parts water). Which solution produces the strongest current? (The acid solution.)

Prepare wider copper and zinc electrodes than the ones used in the previous experiment. Place them in the hydrochloric acid solution and compare the difference in the amount of current produced when the size of the electrodes is increased. (More current will be produced.)

Make a two-cell chemical battery as shown in Fig. 36.3. Observe the deflection of the needle on the galvanometer produced by this battery of two cells. Compare the amount of current produced by the two-cell battery with the amount generated by the single cell. (The two-cell battery will generate more electricity than the one cell will.)

Remove the electrodes from the acid solution. Wash and rinse them thoroughly in water before touching them. Observe the *discoloration* on the two zinc electrodes. Note that the copper plates *are not discolored.* Scrape the discolored ends of the zinc plates with a knife and examine the black powder that is removed. This black powder is a chemical compound called *zinc chloride.*

Fill the container approximately ½ full with the acid solution. Replace the 4 electrodes in the solution. Observe that the two-cell battery generates more electricity than it did when the container was ¼ full. Why? (Because more of the surface of the electrodes is covered by the acid solution, more electrons will collect and flow from the zinc plates. An increase in the number of free electrons increases the electromotive force or voltage and a larger current will flow through the circuit.)

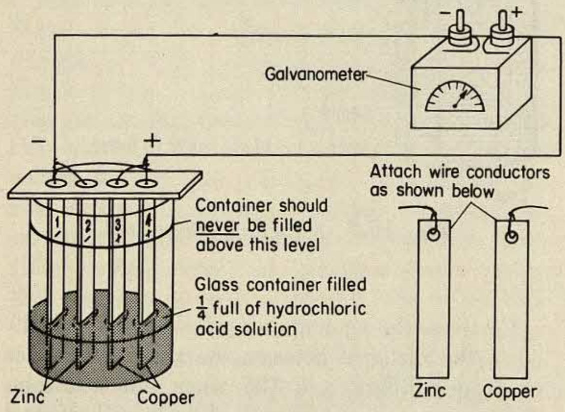

–
+
Galvanometer
–
+
1
2
3
4
Container should never be filled above this level
Glass container filled ¼ full of hydrochloric acid solution
Zinc
Copper
Attach wire conductors as shown below
Zinc
Copper

Fig. 36.3 A two-cell chemical battery wired in parallel, minus (−) to minus (−) and plus (+) to plus (+).

Fill container to highest safe level indicated in Fig. 36.3 (about 2 inches from top of container) to find out whether the battery will generate more electricity than it did when the electrodes were only partially covered with the acid solution. (There will be more current.)

Help the students to summarize the results of these experiments and draw tentative conclusions.

3. What are some of the methods that are used to produce current electricity?

Ask the pupils to list devices that generate electricity. Their list should include some of the following: (1) chemical cells and batteries; (2) fuel cells; (3) generators; (4) magnetohydrodynamos; (5) photoelectric cells; (6) solar cells; (7) thermocouples. Find out whether the pupils can explain how each of these devices generates current electricity. (See Table 36.1.) Ask the pupils to check textbooks, reference books, magazines, and newspapers for explanations. Help them to plan experiments they can do to demonstrate these various devices. Also obtain as many of the listed devices as possible.

The following activities can be used to increase the pupils' understanding of these different ways of producing electricity.

Chemical Cells. Review some of the experiences in Inquiries 1 and 2 in this chapter.

Fuel Cells. Obtain photographs of fuel cells by writing to the National Aeronautics and Space Administration. See Chap. 5 for address.

Generators. Repeat some of the experiments in Chap. 19.

Magnetohydrodynamos. Look for information about this new way to produce electricity (now used in England).

Photoelectric Cells. Examine an exposure meter, which a photographer uses to measure the amount of light before he takes a picture. This meter is composed of a photoelectric cell and a galvanometer. Expose the meter to varying amounts of light and compare the differences in the meter readings.

The bulb-type photoelectric cell is often called an electric eye. Obtain a demonstration kit that contains this type of cell and a 6 volt doorbell and a 110–120 volt lamp bulb and receptacle. Have the pupils use the directions in the kit to help them wire the doorbell in the circuit so that it will ring when the light from the lamp bulb shines through the window of the photoelectric cell. Ask one pupil to stand between the cell and the lamp. What happens? (The bell will stop ringing. When the pupil moves away from the light, the bell will ring again.) Have the children take turns holding various things, such as one of their hands, a piece of black paper, and a piece of white paper between the lamp bulb and the photoelectric cell. Explain what happens.

Table 36.1
HOW DIFFERENT DEVICES PRODUCE CURRENT ELECTRICITY

Device	How Electric Current Is Produced
Chemical cells	A chemical cell contains an *electrolyte* (either a salt or acid solution) and *two electrodes* (two different kinds of electrical conductors). Chemical action between the electrolyte and one of the electrodes causes the negatively charged electrons of some of the atoms to be released. These electrons collect on the electrode from which they were released. When this excess of *free* electrons (negatively charged particles of electricity) collect on one of the electrodes, they cause it to become *negatively charged.* This electrode is called the *negative electrode* or *cathode.* The other electrode becomes the *positive electrode* or *anode.* The negative electrons on the cathode produce a repulsive force. (Like charges *repel* and unlike charges attract.) When a conductor connects the two electrodes, this repulsive force called electrical pressure causes the electrons to move from the cathode (place with the greater amount of electrons) through the conductor to the anode (place with fewer electrons). When electrons move through a conductor, an electric current is produced. The length of time during which the chemical action in some kinds of chemical cells generates a current of electricity can be extended by a process called "charging." In this process, direct current electricity is used to "store" (reactivate) chemical energy in storage batteries and some of the newer types of dry cells. In turn, when the storage battery or this type dry cell is used, the chemical energy produces electrical energy.
Fuel cells	A fuel cell consists of four parts: (1) fuel; (2) oxygen; (3) an electrolyte; and (4), a load or a resistor. Some satellites use fuel cells to generate electrical power. In these fuel cells, the fuel used is hydrogen. Both the hydrogen and oxygen, at extremely low temperatures, are stored as liquids in tanks. Heaters gradually change these two liquids into hydrogen and oxygen gas. Each gas moves into an individual section in the fuel cell. These sections are separated by an electrolyte. The electrolyte causes the atoms of hydrogen gas to *release electrons.* These free electrons *move through a circuit containing the electrical components (load)* to the oxygen section of the fuel cell. Here the oxygen atoms *take on the free electrons.* The movement of these free electrons from the hydrogen through a circuit containing motors, lights, and so on, to the oxygen section is the electromotive force or voltage. The hydrogen atoms' lost electrons move through the circuit to the oxygen atoms, where the two react chemically to produce water and release heat. Atoms that *either lose* or *take on electrons* are called *ions.* Therefore, it is really the *hydrogen ions* that *move through the circuit* to the *oxygen ions* where the two react chemically to produce water and release heat. Fuel cells as sources of electrical power may become practical for remote areas where cheaper sources of power are not available. It is also possible that fuel cells may be used in cases of power failure in industrial areas.
Generators	A current of electricity (movement of electrons) is *induced* when either a magnet is moved through a conductor or when a conductor is moved through the magnetic field that surrounds a magnet. In each case, the electrical pressure is produced by the distortion (called "cutting") of the lines of force in the magnetic field. (See Chap. 19, Inquiry 8.)
Magnetohydrodynamos	A jet of burning gas so hot that it becomes a charged plasma is sent through a magnetic field. This is a process by which electricity can be generated without heavy, friction-bound turbines.

Table 36.1 **(*cont.*)**

Photoelectric cells	There are several kinds of photoelectric cells. One kind is called a photronic cell. When it is designed to measure the amount (intensity) of illumination in buildings, it is referred to as a photometer and when it is designed to determine the correct light exposure that camera film should have to obtain a good picture, it is called an exposure meter. This kind of cell is composed of a thin transparent film of selenium, a "light-sensitive" metal on a layer of a less "light-sensitive" metal alloy of nickel and iron. When light strikes the selenium, some of the light energy is absorbed. The absorption of this energy makes it possible for some of the electrons to break away from the selenium atoms and flow in a circuit. The current flowing through the circuit causes a deflection of the magnetic needle on the dial of a galvanometer. Another kind of photoelectric cell commonly called an electric eye is used to control the opening and closing of electrical circuits. This cell consists of a glass bulb that has two outside terminals. One terminal is connected to a ring-shaped conductor inside the bulb. The second terminal is connected to a metallic coating on the inside surface of the glass bulb. With the exception of a small clear glass window area, the entire inside surface of the glass bulb is covered first with a coating of silver and then with a second coating of potassium. After the air in the bulb is evacuated, a small amount of argon gas is introduced. No current flows through a circuit into which the cell is wired unless either infrared or visible light waves pass through the small window and strike the potassium. Whenever either infrared energy or visible light energy is absorbed by the potassium, the potassium gains heat energy and releases electrons. These free electrons produce the electrical pressure necessary to cause a current of electricity to flow through the circuit.
Solar cells	The cells in a solar battery produce electricity when light strikes them. Each cell is composed of two thin slices (slabs) of a silicon crystal. The slices have been specially treated so that the positive charges (called holes) in one slab and the negative charges (electrons) in the second slab move in toward each other when light strikes them. As a result, a strong electric field is formed between the two slabs of the crystal. Because this field resists the flow of electrons directly across one piece of silicon to the other, the electrons move through the conductor of the circuit into which the cell is wired. This movement of electrons provides the electrical energy required to operate electrical instruments that are connected in the circuit.
Thermocouples	A thermocouple consists of two different metals that vary in their heat conductivity. Place a strip of one metal parallel to a strip of a second metal. Fasten the two left ends together. Connect the opposite ends with wire into a circuit. When the two attached ends of the metal strips are heated, the better conductor releases electrons. These free electrons provide the electrical pressure necessary to move them through the circuit to the poorer conductor. Although thermocouples generate only a very small current, they are valuable devices because the current generated is a measure of the amount of heat converted to electricity. Thermocouples are commonly used to measure very high or very low temperatures in which mercury would either evaporate or solidify. Watch for news about thermoelectric generators that operate on the same principle as a thermocouple.

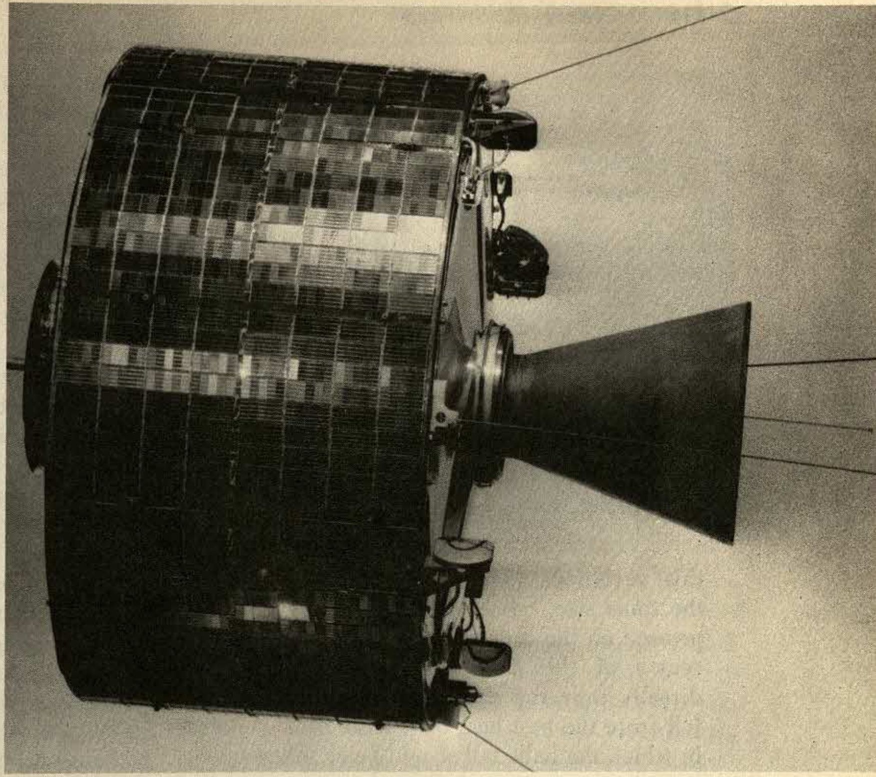


Fig. 36.4 Solar batteries are used in this satellite. *Courtesy NASA.*

(Each of these things will cause the bell to stop ringing because it blocks the light from the cell.)

Solar Cells. Look for pictures of solar cells and batteries in textbooks, reference books, and current magazines.

See Fig. 36.4. The number of solar cells used on recent satellites and space vehicles can be learned by writing to NASA.

Some small portable radios use solar cells to generate electricity. Borrow one of these radios to demonstrate that the sound volume varies with the amount of light shining on the solar cells. Solar cells can be purchased from electronic supply houses for experimental purposes.

Thermocouples. List some of the metals that are very good conductors of heat and some that are poor conductors of heat. The pupils' lists will provide some indication of whether they know that metals vary in their ability to conduct heat. Guess in which metal container, an iron or an aluminum one, water will first reach the boiling point. (Water in an aluminum dish will boil sooner than an equal volume of water in an iron dish.) If pupils make incorrect guesses, obtain similarly shaped iron and aluminum dishes, put equal amounts of water at the same temperature in each, and heat until the water boils. The experiment will be more convincing if the pans can be heated simultaneously on a two-burner electric hot plate. If this is not possible, heat each in turn on the same burner. The burner should be allowed to come to full heat before the pans are set on it. Record the length of time it takes for each dish to bring the temperature of the water to the boiling point. Make certain the pupils discuss and provide the controls needed to make the results valid.

Obtain a heat conductivity apparatus with an assortment of metal rods on it. One type of heat conductivity apparatus is shown in Fig. 36.5. Carpet tacks can be used instead of beeswax balls, if tacks are easier to obtain. Dip the heads of the tacks in melted paraffin. Let the paraffin harden and press each tack firmly against the rods in the positions indicated by the beeswax balls. Note that the underside of the metal disc has a concave area in the center. Hold the conductivity apparatus so this concave portion is directly over the flame. (See Fig. 36.5.)

Keep a record of the order in which the balls fall. Repeat the experiment several times. Before each new trial, cool the rods in cold water. Compare the results of each trial. There may be a variation in the results. Discuss the reasons for

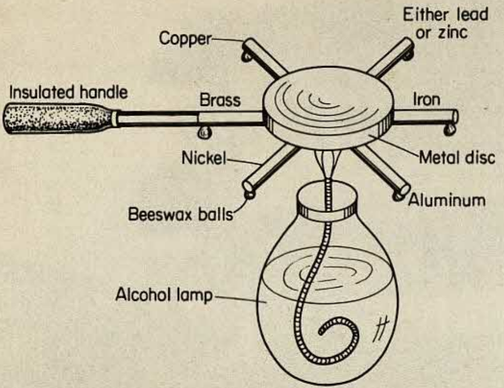


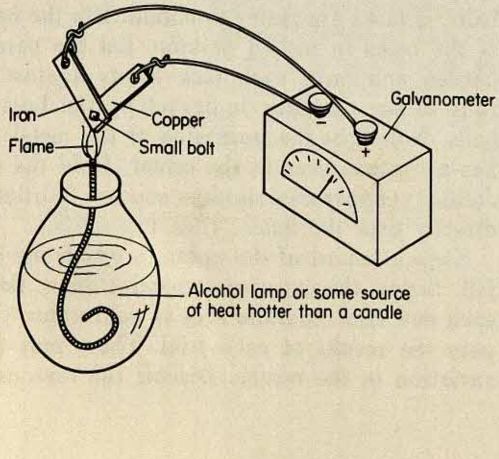
Fig. 36.5 Apparatus for testing the relative heat conductivities of various metals.

this variation. (The balls may not have been the same size. Some of the balls may have been pressed on the rods more firmly than others. The center of the disc may not have been held directly over the flame.) The beeswax ball will fall from the best heat conductor first. The order in which the balls fall should be as follows:

1. copper
2. aluminum
3. brass
4. iron
5. nickel
6. lead or zinc

Collect the materials to make a thermocouple like the one shown in Fig. 36.6. Use experiences similar to the following ones to develop the concept that heating the two different metals in the thermocouple produces a current of electricity. Let the children have the fun of guessing why this device is called a thermocouple.

Fig. 36.6 How to find out whether electricity will be generated when two different metals are heated (see text).



Obtain a strip of copper and a piece of iron or steel. Each should be about 1 inch wide and 4 inches long. Punch a hole in both ends of each strip of metal. Fasten them together as shown in Fig. 36.6. Connect the opposite end of each strip in a circuit with a galvanometer as shown in Fig. 36.6. In a hot flame heat the ends of the metal strips which are fastened together. Note that the galvanometer needle is deflected. The deflection of the needle indicates that a small amount of electricity is generated.

Avoid the possibility of developing a misconception, by discussing the difference in the meaning of the words *heat* and *temperature.* (A thermometer *measures temperature* and *not heat.* The heat in an object can be measured, if *both* the *temperature* and the *volume,* or mass, of the object is known.) What word is frequently used to describe two married people? (A couple.) Why is the word thermocouple a meaningful name for this bimetallic device that produces a current of electricity when it is strongly heated? (Because *heat* is applied to the *ends* of two *metals* that are *coupled,* or fastened, *together.*)

Use textbooks and reference books to find the names of some of the ways in which thermocouples are used. (See Table 36.1.)

Experiment to find out whether it is necessary to use *two different kinds of metals* to produce current electricity. Substitute a second piece of copper for the iron or steel shown in Fig. 36.6 and check to find out whether a current is produced. Remove the two copper strips and replace them with two iron strips. Results? (No current will be produced in either case.)

4. What is a Leyden jar? How is it charged? Why is a Leyden jar called a condenser or capacitor?

In Chap. 18, there are a variety of experiences with frictional electricity. Select several of the experiences suggested there and repeat them. Develop the concept that any *insulator,* which is charged with frictional electricity, will store the electrical charge for a short period of time.

Compare the differences in the amount of electricity that is stored on the surface of a charged balloon when the balloon is rubbed once,

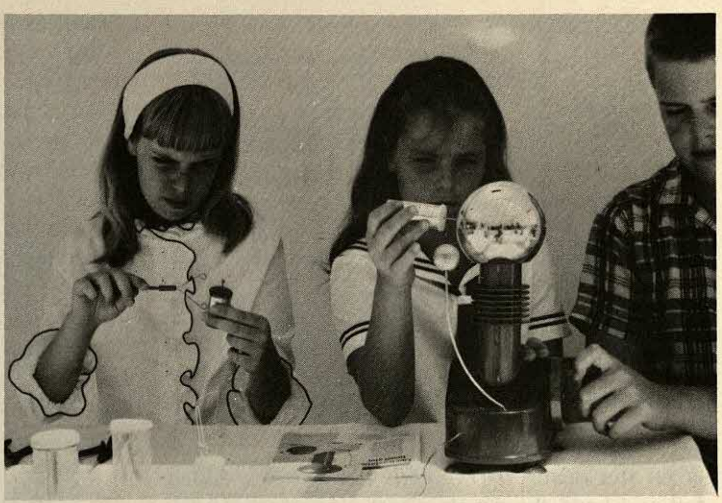


Fig. 36.7 The girl on the right holds a small homemade Leyden jar which is being charged by a small Van de Graaf generator. The other girl is about to discharge a Leyden jar with a homemade discharge yoke.

twice, three times, or six to a dozen times. As more and more of the charges accumulate on the surface of the balloon, the attraction becomes stronger between it and a second balloon that *becomes charged by induction* if it is suspended *in the electric field* of the rubbed balloon. Ask the pupils to explain why the second balloon becomes charged. Also, ask them to state the kind of charge the second balloon has. (An electric charge is induced on the second balloon because it is in the field of attraction, electric field, of the rubbed balloon. The second balloon will have an opposite charge, or a charge that is unlike the charge on the rubbed balloon because unlike charges of electricity attract.)

Rub one of the balloons at least a dozen times and press it firmly against the wall. The balloon will cling to the wall for a minute or longer. (The length of time depends upon the size of the balloon, the size of the charge, and the weather. The balloon will lose its charge sooner on a very humid, or rainy, day than it will on a day when the humidity is low.)

Find out how many of the pupils have received an electrical shock when they walked across a rug and touched a metal door knob or some other metal object. The children's bodies were storing electrical charges that their shoes had removed from the rug. The electrical charges were *discharged* (released) when conductors of electricity were touched.

Devices that store electrical charges on their surfaces are called *condensers*. Another name for a condenser is a *capacitor*. Condensers used in radios, televisions, and so on, are usually called capacitors. One kind of condenser which is easy to make and understand is called a Leyden jar. Leyden jars, usually charged by electrostatic generators, are primarily used in science laboratories (see Fig. 36.7). However, *understanding* how the Leyden jar stores electrical charges is basic to understanding other types of condensers or capacitors.

There are two different kinds of electrostatic generators that are commonly used in science laboratories. One kind is called the Van de Graaf generator. (See Fig. 36.7.) The Van de Graaf generator shown in Fig. 36.7 was assembled from an educational science kit. This small generator is safe for children to operate without adult supervision, because it generates a low voltage.

Try to obtain a Van de Graaf electrostatic generator. Read the manual that accompanies this machine. Help the pupils to do some of the experiments suggested in the manual. After the pupils have had opportunities to observe what this electrostatic generator can do, organize them into three study groups. Help each group to select one of the three following groups of inquiries and to prepare and present solutions for them.

Inquiry group 1

How Can a Small Leyden Jar Be Made? See Fig. 36.8. First wrap foil strip (a) around the *outside* of the plastic pill bottle to form a coil shaped to the size of the bottle. Make certain that the *end of the aluminum foil with the cut in it*

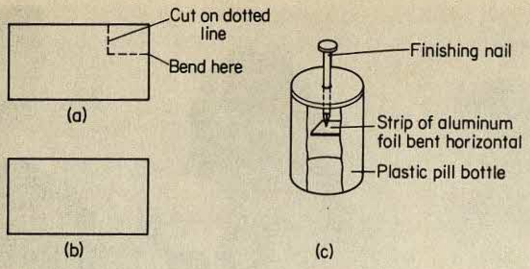


Fig. 36.8 How to make a small Leyden jar which can store a small amount of electricity (see text). Part (c) is a cutaway view of the jar showing how the cut in the strip of aluminum foil allows the flap to be bent to a horizontal position inside the jar.

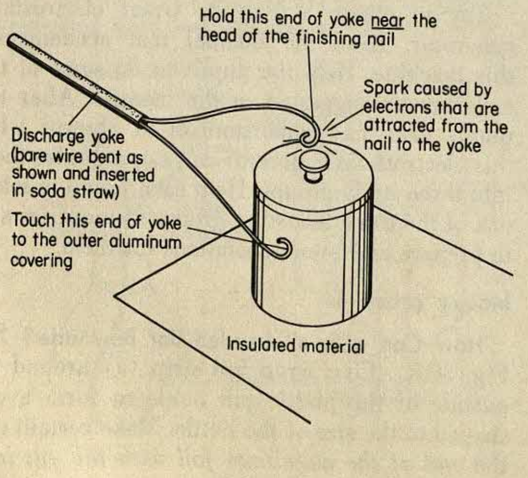
is on the *inside of the coil.* Remove the coiled foil and bend the cut strip into a horizontal position. Place the coiled foil *inside* the bottle and allow it to expand until it fits tightly against the inside wall of the bottle. Use gummed tape in at least two places to hold the foil against the wall of the bottle. This can be done by pressing one piece of tape *above* the horizontal strip and the second piece of tape on the opposite side.

With a piece of gummed tape fasten aluminum foil strip (b) around the *outside* of the pill bottle. Force the point of a 2-in. finishing nail through the plastic cover of the pill bottle. Push the cover on the bottle and adjust the nail until you can feel it touching the horizontal strip.

How Can the Leyden Jar Be Charged? See Fig. 36.7.

How Can a Discharge Yoke Be Made for the Small Leyden Jar? Cut a piece of bare wire about 8 in. long and bend it to form a yoke. The distance between the two coiled ends of the wire yoke should be adjusted so that one of the coils will touch the outside wrapping of foil on the small Leyden jar at the same time that the other coiled end is brought near the head of the nail on the top of the jar. Insert the bent wire yoke as shown into one end of a soda straw which is at least 5 in. long. See Fig. 36.9. This discharge yoke consisting of a bent bare wire and an insulated soda straw handle can be used to discharge the small Leyden jar. By bending the free ends of the two wires farther apart, the yoke can also be used to discharge a large Leyden jar.

Fig. 36.9 How to discharge a charged Leyden jar.


Hold this end of yoke near the head of the finishing nail
Spark caused by electrons that are attracted from the nail to the yoke
Discharge yoke (bare wire bent as shown and inserted in soda straw)
Touch this end of yoke to the outer aluminum covering
Insulated material

Charge the small Leyden jar on the small Van de Graaf generator. Set it on an insulated table. Find out how long it will store the charge. If the Leyden jar is still charged, a small spark can be seen when the discharge yoke is held in the position shown in Fig. 36.7.

What Is the Correct Way to Use the Discharge Yoke? See Fig. 36.9.

Inquiry group 2

How Can a Larger Leyden Jar Be Made? See Fig. 36.10, and proceed as follows. Cut a paper pattern to fit both the inside and outside walls of a wide-mouthed pint jar. Also cut a pattern to cover the inside and outside bottom surfaces of the jar. The pattern for the inside wall lining should be cut into 4 pieces and each piece should be large enough to overlap the pieces adjacent to it. Lay the paper patterns on a piece of aluminum foil and cut around them. Spread glue on each piece of the aluminum foil. Use the eraser end of a pencil to stick the foil to the inside surfaces of the jar. Also glue foil to the outside of the jar. Wind the bare copper ground wire around the outside of the container as shown in Fig. 36.11. Tightly coil a 12-in. long piece of bare copper wire around a stove bolt or a large nail. Make a cardboard cover for the jar. Straighten one end of wire and insert it through the center of the cardboard. Attach to it a chain of paper clips long enough to drag on the bottom of the jar.

How Can a Larger Leyden Jar Be Charged? Touch the end of the coiled wire to the charged hollow sphere of a Van de Graaf machine. See Fig. 36.7. Follow precautions when charging the

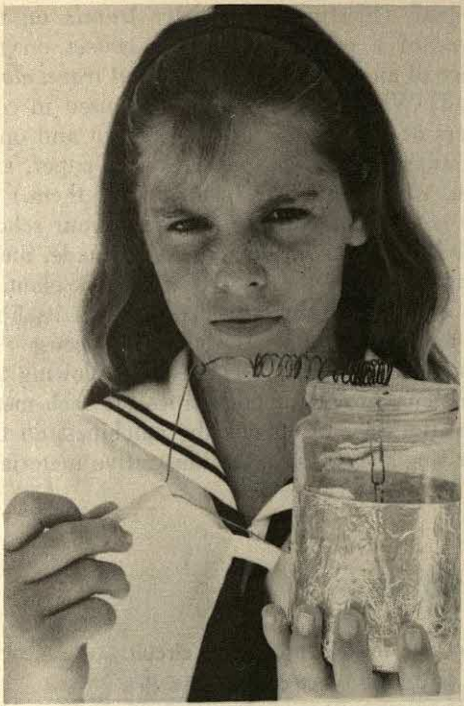


Fig. 36.10 The girl is discharging a large homemade Leyden jar with a large homemade discharge yoke.

jar. Set the charged jar on an insulated table. Find out how long it will hold a charge.

What Precautions Should Be Taken When Charging the Large Leyden Jar?

PRECAUTIONS

1. **Hold the Leyden jar in *one hand*. Do not touch the coiled wire on the top of the jar while holding the jar. You will get a severe electrical shock if you do.**
2. **Place the Leyden jar on an insulator such as a wooden table top until you are ready to discharge it.**
3. **Avoid shocks by keeping your hands away from any metal parts on the machine *while it is in operation* and *until the machine has been discharged.***

How Can the Large Leyden Jar Be Discharged?

See Fig. 36.10.

Inquiry group 3

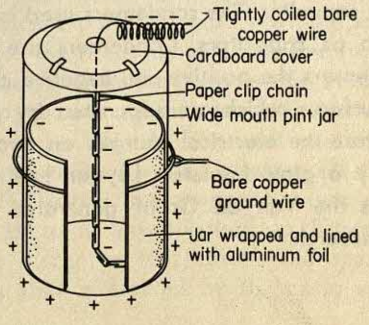
How Does a Leyden Jar Store Electricity?

Why Can a Large Leyden Jar Store More Electricity Than a Smaller One Can?

The electrons travel from the electrostatic machine to the surface of the coiled wire and along the surface of the chain of paper clips to the inside surface of the foil lining. As more and more electrons (negative charges) collect on the inside aluminum lining, a stronger and stronger *positive charge* is *induced* on the aluminum foil on the outside of the jar. (Opposite, or unlike, charges of electricity attract each other.) The excess electrons on the inside lining of the foil repel the electrons on the foil on the outside of the jar. (Like charges of electricity repel each other.) The repelled electrons move along the surface of the bare copper ground wire and into the ground. See Fig. 36.11.

A Leyden jar stores electricity for longer periods of time than such electrically charged objects as balloons, pith balls, and metal foil electroscopes. In the Leyden jar, the insulation between the unlike charges is the *glass jar*. Glass is a better electrical insulator than air. *Air* is the insulator between the balloons, pith balls, and the metal foil strips in an electroscope. Even a small Leyden jar like the one described in Fig. 36.8 holds a charge for as long as 24 hours under favorable conditions. They also store a larger charge that produces a stronger electromotive force (voltage) or field of attraction between the unlike charges. They can store this larger charge because the two charges are so well insulated from each other. A large Leyden jar will store more electricity than a smaller jar because there is more surface on which the unlike charges can collect. Have the group of

Fig. 36.11 Cutaway figure showing the electrical charges on both the inside and outside surfaces of the Leyden jar. The ground wire is long enough to be attached to a water pipe, faucet, or radiator.



children who study this problem plan some experiments to show that larger charges collect on objects that have more surface. Also, ask this group to be prepared to discuss the answers to these questions when they make their report to the class: (1) Why was a glass container instead of a metal container used for the Leyden jar? (Glass is a good electrical insulator and prevents the electricity from traveling between the two oppositely charged surfaces of the foil. A metal container is a good conductor of electricity. It would conduct the negative charges from the inside lining of foil to the outside lining and discharge the jar.) (2) Why was *bare wire* instead of *insulated wire* used for collecting the negative electrical charges from the electrostatic machine? (Frictional electricity *travels* on the *surface* of a conductor. It will *collect* on the *surface* of an *insulator* but it *will not travel along it.*) (3) What other insulators are used in condensers or capacitors? (Try to obtain and open some capacitors. Mica, paper, waxed paper, and so on, will be used as insulators in them.) If there is a manufacturing plant near your school where condensers or capacitors are made, make arrangements for the class to visit this plant.

As each of the three groups presents its findings to the class, help the class to discuss and evaluate each of the presentations. Following the discussions, provide opportunities for each member of the class to operate the machines, do the experiments, and study the illustrative materials.

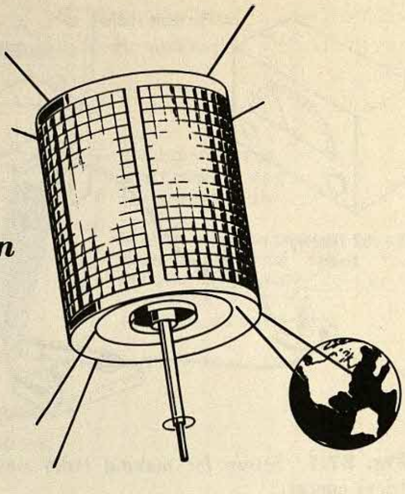
CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. A current of electricty is produced when electrons travel through a circuit. The electrons travel through the circuit from the negative electrode of the dry cell to the positive electrode. The electromotive force or voltage produced by an excess of electrons on the negative electrode of the dry cell causes electrons to travel in a circuit. The electrical pressure necessary to cause electrons to flow in a circuit containing a dry cell occurs because the zinc and carbon metals in the cell react differently to the chemicals in the cell.

2. A chemical battery will produce a stronger current of electricity if the distance between the electrodes is decreased and if the size and number of electrodes that are exposed to the chemical solution is increased. A battery is composed of two or more cells.

3. There are a number of different methods that are used to generate current electricity. These different methods are utilized in such devices as chemical cells, fuel cells, generators, magnetohydrodynamos, photoelectric cells, solar cells, and thermocouples. In each device, freed electrons cause an electrical pressure or voltage that moves electrons in the circuit. Current electricity is the movement of electrons through a conductor.

4. A Leyden jar is one kind of electrical condenser. A condenser is also called a capacitor. The condensers used in radio and television sets are usually referred to as capacitors. Condensers are devices that store electrical charges. In condensers the positive and negative charges of electricity are stored on two metal surfaces which are separated by insulating material. The homemade Leyden jars store the electrical charges on two aluminum foil surfaces, which are separated by a glass insulator. Leyden jars can be charged by electrostatic machines, such as the Van de Graaf generator. Electrostatic generators are used in nuclear research.



Chapter Thirty-Seven

Radio and Television

How to Produce and Select Radio Waves

INQUIRIES

1. What kinds of electrical devices can be used to produce radio waves?
2. What devices make it possible to select different radio stations?

1. What kinds of electrical devices can be used to produce radio waves?

Build the concept that any electrical device that produces a spark generates radio waves. In Chap. 36, Inquiry 4, the class charged Leyden jars with the electricity generated by electrostatic machines. These generators are sometimes called "spark machines." Have the pupils observe the spark that seems to jump from the Van de Graaf electrostatic generator.

Darken the room and operate the machine again. Place a portable radio near the machine and "tune" the radio to one of the low frequency wave bands and listen to the static emitted by the radio speaker. Tune the radio to a high frequency wave band and find out whether static will also be emitted by the speaker. (It will.)

Operate the machine again. This time observe whether there is any relationship between the electrical discharge that causes the spark and the static that is emitted by the radio speaker.

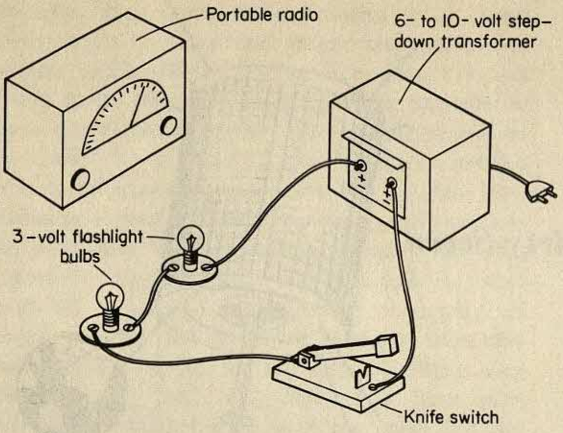


Fig. 37.1 Set-up for making radio waves with electrical energy.

(A loud crackling static sound will be heard *each time* the discharge occurs.)

In this inquiry and in several succeeding problems, a pegboard is used for wiring electrical devices that will produce radio waves with the energy provided by two 1½-volt, size D flashlight dry cells. Ask one child to cut a piece of pegboard 8 inches by 12 inches. As the pupils set up the pegboard circuits and observe the results of each of the experiments with these circuits, ask them to keep a record of their findings.

Obtain either a 6–10 volt bell transformer or one of the small transformers that are used to operate toy trains. Select several of the pupils to wire the step-down transformer into a series circuit like the one shown in Fig. 37.1.

Plug the transformer into one of the house circuit outlets and place a portable radio one to three feet from the series circuit. Tune the radio to one of the low frequency wave bands (550–800 kilocycles). Close the knife switch and listen for the noise of static being emitted by the radio speaker. (There will not be any.) Rapidly open and close the knife switch and listen again. Each time the switch is opened and closed, a click of static will be heard coming from the radio speaker. Find out whether the radio speaker will emit this static when it is tuned to a higher frequency band. (It will.)

Remove the two flashlight bulbs and their receptacles from the circuit. In their place, connect a 6-volt doorbell. Remove the metal box that is attached directly below the doorbell sounder (resonator). Close the knife switch and listen for static coming from the radio speaker. Try tuning the radio to different wave frequencies and listening again. Static will be heard at all the wave frequencies in the AM radio wave band. (Frequencies from 550–1600 kilocycles.) Why? Encourage the pupils to guess. If the class observes very closely, they will see a small spark appear to jump from the armature of the bell to the contact breaker. (See Fig. 19.9 for a diagram of the doorbell.) Apply the experiences the pupils have had with the electrostatic machine. This application should help them to guess that radio waves of *many frequencies are emitted by the spark into the space surrounding the spark.*

Encourage guesses as to why the circuit containing the flashlight bulbs emitted radio waves only when the knife switch was opened and closed. (The switch is a circuit breaker.) Reconnect the flashlight bulbs in the circuit and repeat the experiment again to see whether any one can observe the *tiny spark* between the blade of the switch and the contact points. The spark will be difficult to see unless the experiment is tried in a very dark place. Opening and closing the knife switch produces tiny sparks which produce radio waves. These waves travel through the space between the knife switch and the radio where they are received and made audible as static.

Set up the circuit as shown in Fig. 37.2.

1. The antenna wire should be at least 20 feet long, and one end of it should be attached to a support that is near the ceiling. Bell wire that is insulated with plastic can be used for the antenna wire. Remove 3/4 of an inch of insulation from both ends of the bell wire. Wind one end of the *bare wire* around the machine screw to which the positive lead from the dry cell battery is attached. Fasten the wire securely with a nut. Let at least 6 inches of the opposite end of the antenna wire hang free from the support to which it is attached. No *metallic object* should come in contact with the bare wire hanging from the support.
2. The length of the ground wire depends upon the distance to the closest water faucet or radiator. Remove 3/4 of an inch of insulation from one end of the wire. Attach this end to the machine screw to which the wire from the negative terminal of the dry cell battery is attached. Hold the wire in place with another nut. Remove enough insulation from the free

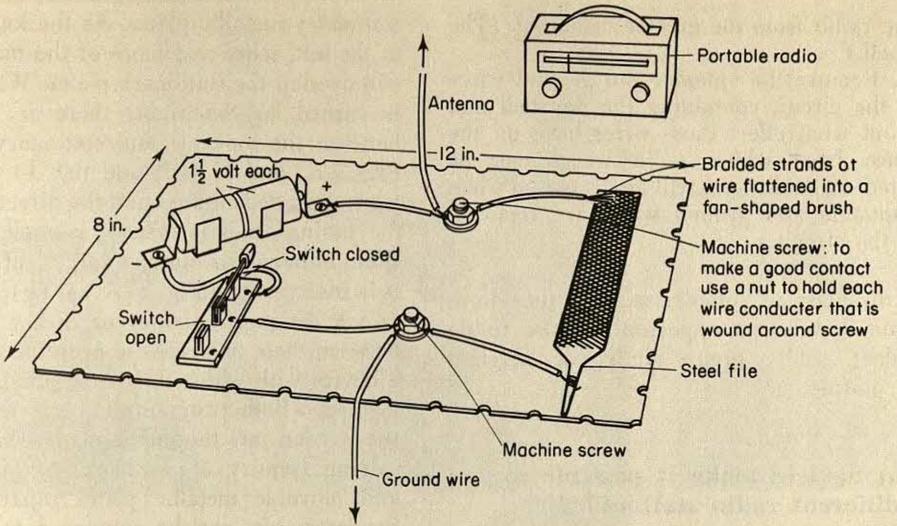

Portable radio
Antenna
12 in.
Braided strands of wire flattened into a fan-shaped brush
1½ volt each
+
8 in.
−
Switch closed
Switch open
Machine screw: to make a good contact use a nut to hold each wire conducter that is wound around screw
Steel file
Machine screw
Ground wire

Fig. 37.2 Set-up for making radio waves with electrical devices that produce sparks.

end of the ground wire to make a good contact with a noninsulated part of the water faucet or radiator.

3. If the steel file used in this experiment is rusted or corroded, use a wire brush to remove enough of the corrosion to make a good contact between the end of the file and the wire conductor from the negative terminal of the battery. Also, remove the corrosion from the side of the file that will be used to produce sparks.

4. Close the knife switch and rub the fan-shaped strands of wire along the file as shown in Fig. 37.2. Observe the *tiny sparks* that are produced as the wire is moved.

5. Set a portable radio approximately one foot away from the file and tune the radio to one of the waves in the low frequency band (550–800 kilocycles). Listen to the static that is produced as the wire is moved along the file. Tune the radio to each wave frequency listed on the dial and use the sparking device again. What happens? (Static will be heard at each of the frequencies. The sparking device releases a *mixture of radio wave frequencies.*)

6. Use the steel file and the fan-shaped strands of wire for a sparking device and find out how far away the radio will detect the mixture of radio wave frequencies. (The distance will vary with the conditions. Fresh or new dry cells will produce more current and the waves will be transmitted to a greater distance.)

7. Turn the tuning knob on the radio to the highest wave frequency listed on the dial (1500–1600 kilocycles). Place the radio at the greatest distance from which the static caused by rubbing the wire on the file can be heard. Record this distance. Tune the radio to the lowest wave frequency and find out how far away the static can be heard. When high and low wave frequencies are produced by equal amounts of electrical energy, which will travel farther? (The low frequency waves.)

8. Detach the antenna and ground wires from the circuit. Experiment to find out what effect the antenna and ground wires have on the distance that radio waves can be detected. (When the antenna and ground wires are connected in the circuit, wave energy can be detected at greater distances from its source.)

9. Remove the steel file from the circuit and substitute an electric doorbell from which the cover of the bell box has been removed. Compare the size of the sparks that appear between the armature and contact breaker in the doorbell with the size of the sparks made on the file with the wire brush. (The bell sparks will be larger.) Compare the intensities of the static produced by the doorbell and by the steel file. Which device produces the more intense static? (The doorbell.) Which device produces stronger radio waves? (The doorbell.) Do longer or shorter sparks produce more intense static? (Longer sparks.) Which device emits radio waves that can be detected

by the radio from the greater distance? (The doorbell.)

10. Remove the antenna and ground wires from the circuit containing the doorbell and find out what effect these wires have on the distance from which radio waves can be detected. (The distance will be decreased when the antenna and ground wires are removed from the circuit.)

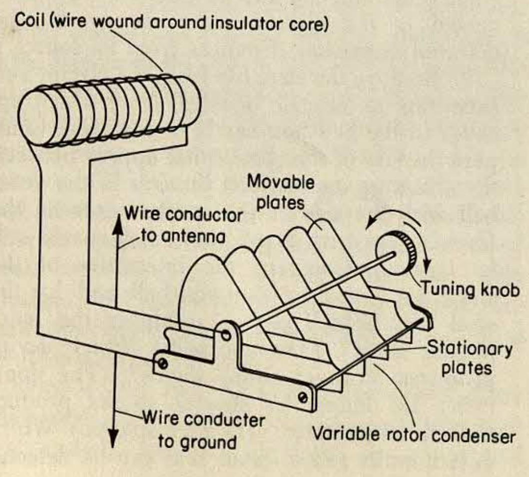
Help the class to summarize what they have discovered. Give them opportunities also to do independent study, group study, or original experimentation.

2. What devices make it possible to select different radio stations?

Obtain one vacuum tube radio and one transistor portable radio. Turn the switch of each of these radios to the off position and remove the back covers. Try to locate the devices in each of these radios that make it possible to select radio programs that are broadcast on different wave frequencies. See Figs. 37.3 and 37.4.

Observe what happens when the tuning knob or program selector is turned to the right. In the vacuum tube radio and in some transistor radios, a series of metallic plates will move upward when the tuning knob is turned to the right and downward when the knob is turned to the left. Notice that these *movable* metallic plates rotate between *stationary* metallic plates. As the knob is turned to the left, more and more of the movable plates will overlap the stationary plates. When the knob is turned to the right, there is less overlap between the movable and stationary plates. See Figs. 37.3 and 37.4(d) and (e). In some transistor radios, depending upon the direction in which the tuning knob is turned, a small hollow tube slides either in or out of a larger tube into which it is inserted. See Fig. 37.4(a), (b), and (c).

Fig. 37.3 Program selector or tuning circuit in a radio receiving set.



Ask the pupils if they can see a resemblance between these two types of program selectors and a device with which they have previously experimented. (Both program selectors are similar to the Leyden jars the pupils made when they were solving Inquiry 4 in Chap. 36. The stationary and movable metallic plates separated by the insulator, *air*, can be compared to the Leyden jars' inner and outer foil-covered surfaces separated by the insulator, glass. The stationary and movable metal foil-covered tubes separated by an insulator of waxed or varnished paper can also be compared to the Leyden jars. Because these program selectors are like Leyden jars, which are *condensers* that store electrical charges, the two types of program selectors are also *condensers.*) Observe how these selectors *differ* from Leyden jars. (The areas of the metallic plates and the areas of the metal foil covered tubes separated by the insulators can be *varied* by turning the program selector knob.) How can these tuning condensers best be described? (Both types are *variable* condensers because the movable part of each *varies or controls* the amount of electrical energy which they store. The movable plate condenser is a *variable rotor condenser.* The movable tubular condenser is a *variable tubular condenser.*)

The air space between the movable and stationary plates in the variable rotor condenser acts as an insulator (called a dielectric) and prevents the electrons stored on the movable plates from traveling across the gap to the stationary plates. Each of the tubes in the variable tubular condenser are covered with metal foil and insulated from each other with an insulator, such as wax- or varnish-coated paper. In this case the waxed or varnished papers are the insulators (dielectrics), which prevent the electrons from traveling across the gap between the two tubes.

Warn the pupils about the unpleasant shocks

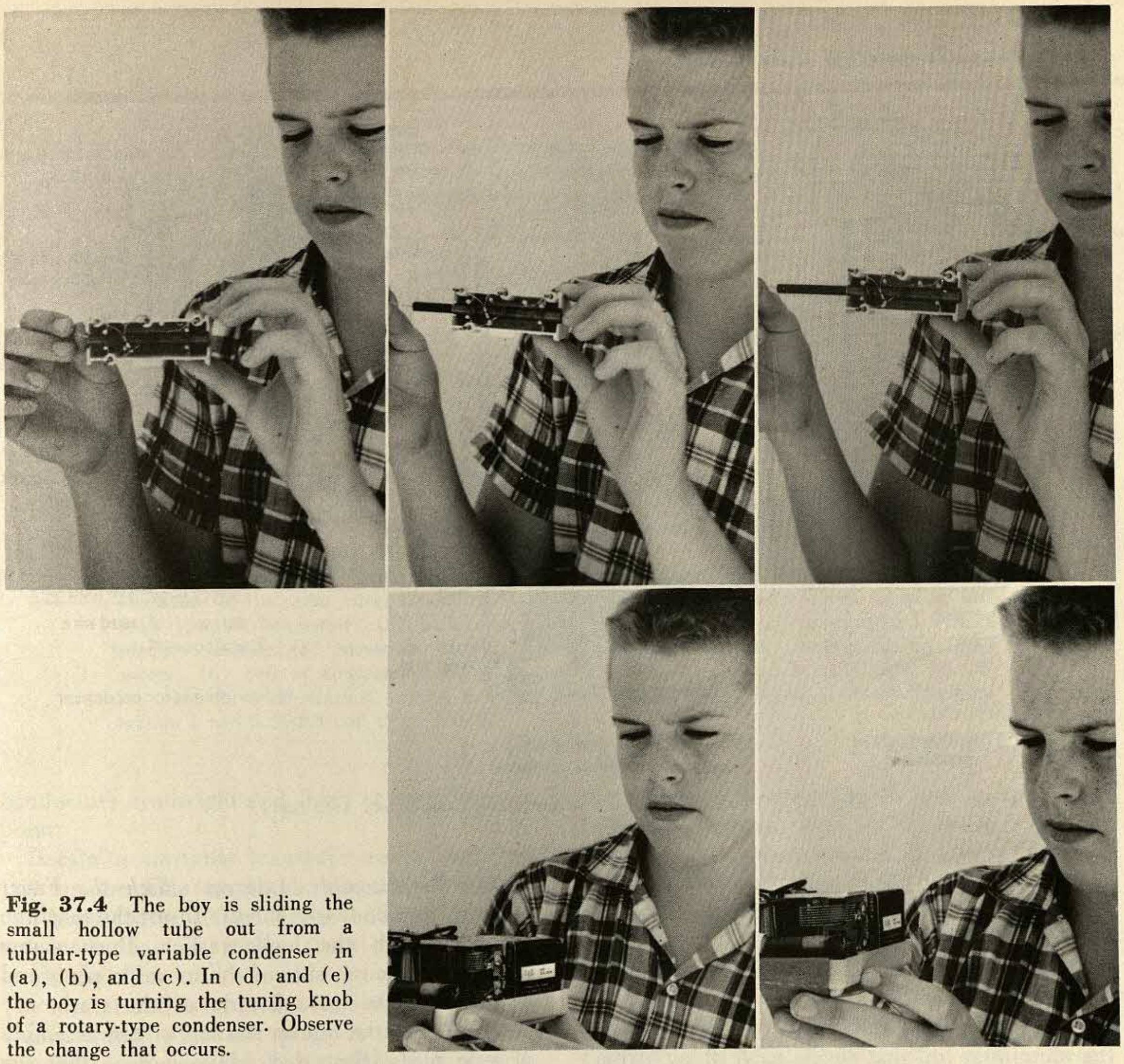


Fig. 37.4 The boy is sliding the small hollow tube out from a tubular-type variable condenser in (a), (b), and (c). In (d) and (e) the boy is turning the tuning knob of a rotary-type condenser. Observe the change that occurs.

they could get if they touch any of the interior wiring or devices inside the radios they are examining. Turn the switch to the *on* position in a radio that has a variable rotor condenser. Tune the radio to one of the lower frequency wave bands. Observe the change in the amount of overlap between the movable and stationary plates as the tuning knob is turned from this low frequency band to higher and higher bands. The plates will completely overlap when the radio is tuned to the lowest wave frequency. There will be less and less of an overlap as the tuning knob is turned to the higher frequency wave bands. When the plates completely overlap each other, the attraction between the negative charges on one set of plates and the positive charges on the second set of plates is very strong. In this position, the opposite charges are equal and they tend to neutralize each other. When there is less overlap, the attraction is less and the charges are not equal.

While examining the insides of these two different kinds of radios, also look for a coil of wire wrapped around an insulator. The variable condenser and the coil are the most important parts of the tuning circuit in a radio or television set.

Build and experiment with a variable rotor condenser in a tuning circuit. The experience will help pupils understand why the condenser in the tuning circuit can select wave lengths of different frequencies. Use the following directions for making a simple variable rotor condenser. (See Fig. 37.5.)

Obtain 2 pieces of wallboard (4 in. × 4 in.). Cut notches in top of wallboard as shown in (a)

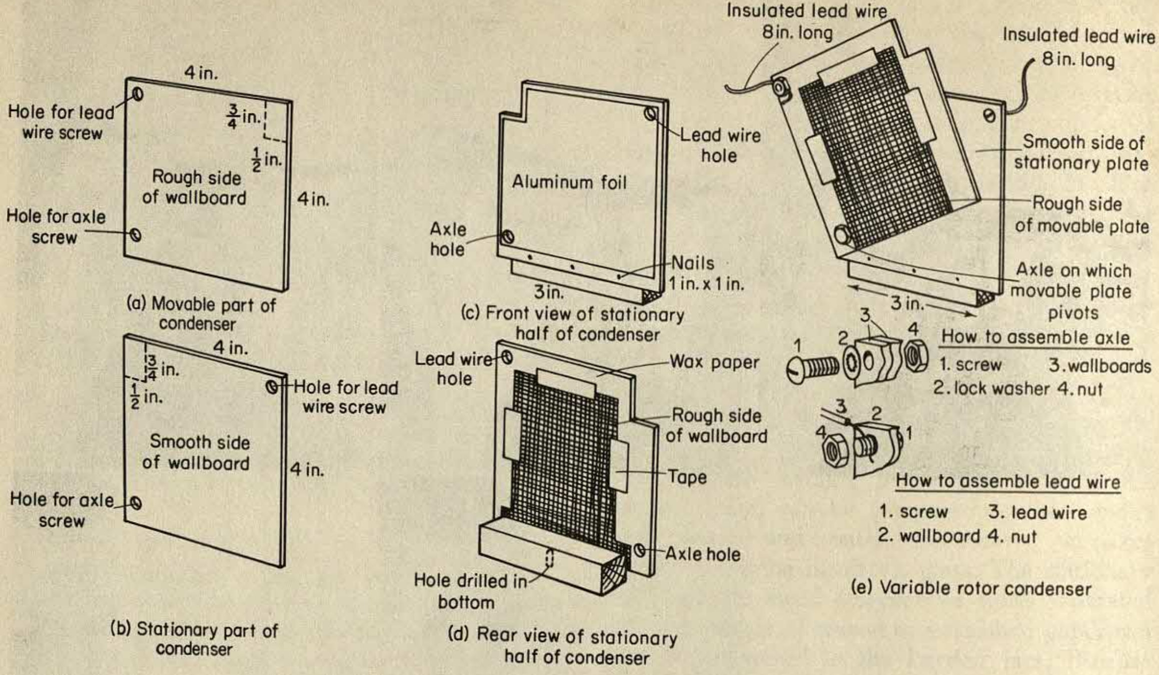


Fig. 37.5 How to make a variable rotor condenser (see text).

and (b). Drill 2 holes in each piece of wallboard. See (a) and (b). The holes should be large enough to insert machine screws.

Glue aluminum foil to the *smooth* side of each piece of wallboard as shown in (c). Use a machine screw as a punch and insert it through the aluminum foil that covers each of the drilled holes. Cut away the aluminum foil from around the *two axle holes only.* Cover the aluminum foil with a piece of wax paper and fold the wax paper over the edges to the back of the wallboard as shown in (d). Drill one hole in a piece of 1 in.×1 in. board to be used later for mounting the completed condenser on a pegboard. Nail this mounting board to the rough side of the stationary part of the wallboard condenser. See (c) and (d).

How to Attach the Lead Wires: On the smooth side of each piece of wallboard, cut away the *wax paper just around the 2 holes where the lead wires are to be attached.* Do this so the machine screw heads *will contact the aluminum foil.* Insert machine screws and wind lead wires around the screws. See Fig. 37.5. Thread nuts on the screws and tighten the screws with a screwdriver.

How to Assemble Axle on which the Front Plate of the Condenser Pivots: Insert the machine screw through the lock washer. Push screw through the rough side of the movable plate and on through the smooth side of the stationary plate. Thread the nut on the screw. See assembly of axle parts illustrated. Make certain that the screw does not touch the aluminum foil on either plate. Tighten machine screw to bring the plates (electrodes) close together. Check to find out whether the movable plate *pivots easily and does not rub* against the stationary plate. If the plate does not pivot easily loosen the nut.

Make a coil like the one for which directions are given in Fig. 37.6. On a pegboard, connect this coil, the homemade variable condenser, a 68 K resistor (K stands for kilohms or 1000 ohms), and a knife switch in a circuit with two 1½-volt size D dry cells. The circuit should be wired as shown in Fig. 37.6. Make certain that the dry cells are fresh. (A fresh cell should release from 5 to 7 amperes of electricity.) A dry cell tester or a direct current ammeter can be used to test the cells that are to be used. Check to see that the circuit is properly connected, that all connections are tight, and that all

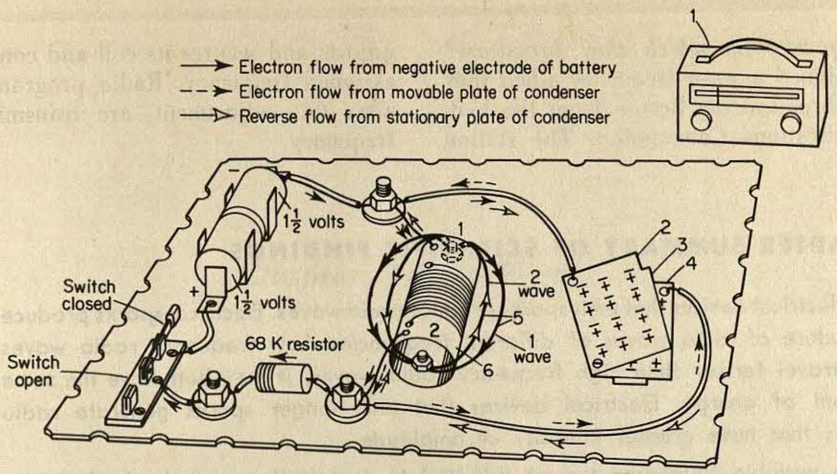

Electron flow from negative electrode of battery
Electron flow from movable plate of condenser
Reverse flow from stationary plate of condenser
1
1½ volts
1½ volts
+
Switch closed
Switch open
68 K resistor
1
2
2 wave
3
4
5
1 wave
6

Fig. 37.6 Set-up and materials for making a simple radio transmitter that controls the frequency of the radio waves transmitted. (1) Portable transistor radio placed 12 in. or less from variable condenser; (2) homemade variable condenser fastened to pegboard with a machine screw; (3) moveable plate; (4) stationary place; (5) electromagnetic radio waves; (6) coil or electromagnetic wave generator—enamel coated magnet wire No. 28 in a 1¾ in. wide winding around a hollow cardboard tube 1½ in. in diameter. Machine screws 1 and 2 fasten coil to pegboard.

conductors are bright and shiny at every contact point.

Obtain a portable transistor radio that can pick up the AM (amplitude modulation) broadcast band (550–1700 kilocycles). Place this radio not more than 12 inches from the homemade condenser circuit.

Turn the radio on and set the volume dial on loud. Pivot the movable plate of the homemade variable condenser until this plate very nearly overlaps the stationary plate. Have one pupil rapidly open and close the circuit with the knife switch. A second pupil should turn the tuning dial of the transistor radio until it clearly picks up the static clicks from the radio waves being transmitted. At what frequency are the waves *received?* Record this frequency. (It will be a low frequency.) What was the frequency of the wave *transmitted?* (The frequency of the wave transmitted is the same as the frequency of the wave received.) Move the movable plate of the homemade condenser until a smaller portion overlaps the stationary plate. Have one pupil again broadcast waves, by opening and closing the switch, and a second pupil turn the transistor radio's tuning dial until the wave frequency (static clicks) is located. Record the frequency band at which they are received. Finally, move the movable plate of the condenser until there is very little overlap with the stationary plate. Repeat the transmitting of the radio waves by opening and closing the switch. Determine their frequency with the transistor radio. What does the homemade variable condenser do to the frequency of the transmitted waves? (When more of the two plates overlap, lower frequency waves are broadcast. When less of the two plates overlap, higher frequency waves are broadcast.)

What determines the frequency of the electromagnetic waves? The frequency of the oscillations depends upon: (1) the size and the overlapping areas of the condenser plates; and (2) the size (diameter) and number of turns of wire in the coil.

Why are low frequency radio waves broadcast from the coil when there is a maximum of overlap between the condenser plates? The great overlap of the plates makes the attraction between the positive (+) charges stored on one plate and the negative (−) charges stored on the other so nearly balanced that there is a tendency for each charge to hold the other, thus delaying the surge of electrons from the condenser to the coil. This delay or degree of delay determines the frequency between the electron surge produced by the dry cell and the surge produced by the condenser.

How do commercial broadcasting stations con-

trol the frequency on which they broadcast? They are assigned a wave frequency when they obtain their broadcasting license from the Federal Communications Commission. The station adjusts and secures its coil and condenser to the assigned frequency. Radio programs broadcast, after this adjustment, are transmitted on this frequency.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Electrical devices that emit sparks produce radio waves. Electrical sparks produce a mixture of radio waves of different frequencies. Low frequency radio waves will travel farther than high frequency radio waves, if they both have the same amount of energy. Electrical devices that emit longer sparks generate radio waves that have greater intensity or amplitude.

2. A variable condenser can be adjusted to control the amount of electricity stored on its plates or tubes. There are two kinds of variable condensers that are commonly used in radios and televisions—the variable rotor condenser and the variable tubular condenser. The amount of electricity that collects on the plates or tubes depends on the distance between them and the size of their overlapping surface areas. The insulators that separate the plates or tubes from each other are called dielectrics. The most important parts of a tuning circuit are the variable condenser and the coil.

Chapter Thirty-Eight

Radio Transmitters and Receivers

INQUIRIES

1. Why are special types of resistors used in radio and television circuits? Why do the resistors used in electronic circuits have different color bands on them?

2. Which radio and television components amplify current? How can it be shown that a transistor amplifies the electrical current?

3. Why are symbols used in diagrams of electrical circuits?

4. How is a transistor made? How does a transistor control and amplify current?

5. How can a radio transmitter that will transmit a continuous oscillating signal be made?

6. How is a vacuum tube made? How does a vacuum tube amplify current? What are some of the advantages and disadvantages of transistors and vacuum tubes?

7. How can a radio transmitter that will emit voice waves be made?

8. How can a simple one-transistor radio set be made or assembled? What is the function of the transistor junction diode in the receiving set?

9. What are the essential parts in radio receiving sets? What is the function of each? What is meant by AM and FM radio? What is a cycle?

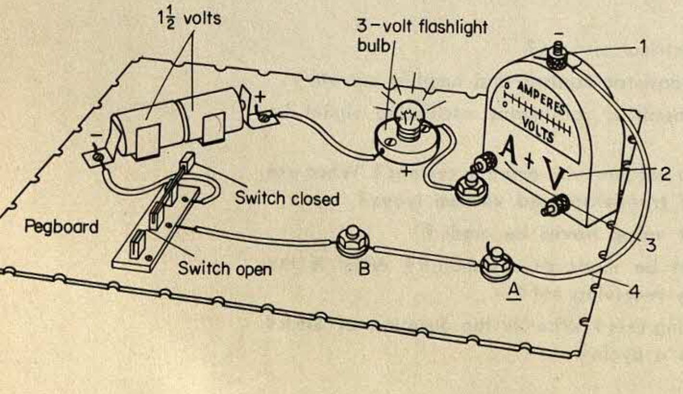
1. Why are special types of resistors used in radio and television circuits? Why do the resistors used in electronic circuits have different color bands on them?

In Chap. 19, the pupils learned that electrical devices such as lamps, electric irons, and toasters are *resistors* because they offer opposition to an applied voltage. They also learned that a resistor is an essential part of every electrical circuit because it controls (holds back) the amount of current that flows in a circuit.

In every radio and television circuit, there are a dozen or more *special resistors* which are used to control the amount of current that flows in *specific parts* of the circuit. These special resistors are in addition to such resistors as vacuum tubes, transistors, condensers and coils.

It is important to the success of each of the experiments with radio circuits that the 1½-volt size D dry cells used be new and at full voltage. It is also important that the *connections to each of the devices* wired in the circuit *be securely made.* Help the children develop the habit of checking the wiring in the circuit to make certain that it is correctly done *before* using the knife switch to close the circuit.

Fig. 38.1 Set-up for using a pocket-size voltammeter to measure the voltage and amperage of an electric current. (1) Pocket-size D.C. voltammeter or battery tester; (2) voltage terminal—to measure voltage press terminal beneath letter V against contact with positive (+) conductor from dry cells; (3) amperage terminal—to measure amperage press terminal beneath letter A against the contact screw that connects the positive (+) conductor from the dry cells; (4) wire lead from voltammeter's negative (−) terminal—hold it firmly against the contact screw that connects the negative (−) conductor from the dry cells.



Obtain a *voltammeter* for testing dry cells. There are several types that are available. One type that is easy to use and relatively inexpensive is shown in Fig. 38.1. A voltammeter can be used to measure both the number of volts (unit for measuring electrical pressure) and the number of amperes (unit for measuring the current flow) in a circuit that uses the electrical energy from dry cells. If a size D dry cell is new, it should have an electrical pressure of 1½ volts and a current flow of 5 to 7 amperes.

In the circuit shown in Fig. 38.1, two size D flashlight cells are connected in series. Without any other electrical devices in the circuit, use a voltammeter to measure the voltage (volts) and the current flow (amperes). To do this, only two changes need to be made in the circuit shown in Fig. 38.1. Remove the flashlight lamp bulb and receptacle from the circuit and connect together the two wires that were attached to the receptacle. If the dry cells are in good condition, the voltage should be approximately 3 and the amperage between 5 to 7.

Reconnect the lamp bulb receptacle and lamp in the circuit and test the voltage and amperage again. The flashlight bulb glows brightly even though the needle reads zero (0) when testing for the number of *amperes* flowing in the circuit. The glowing bulb indicates that *current is flowing through the circuit* and that the flow *is less than 1 ampere.*

When the *voltage terminal* is pressed against the positive contact screw the needle on the dial of the voltammeter will indicate that *less than 3 volts is forcing the current through* the circuit. What causes the voltage drop? (Resistance in the circuit.)

See Fig. 38.1. Wire a 68 K resistor in this circuit between the two lower right-hand screws *A* and *B*. What happens when the 68 K resistor is connected in a circuit with a voltammeter? The voltammeter will register zero (0) amperes and between 0–1 volts. The flashlight bulb will not light. The 68 K resistor holds back so much of the current that neither light bulb nor voltammeter show amperage.

Why must *some current be flowing* in the circuit? Because the voltammeter indicated that there was a voltage of 0–1 volts. If no current were flowing in the circuit the voltage would also have been zero (0).

Have the pupils wire a circuit as shown in

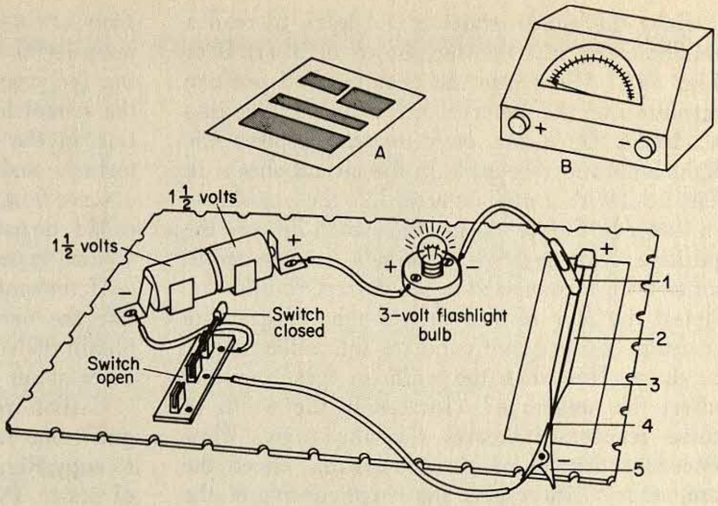


Fig. 38.2 Set-up for testing graphite and carbon resistors. (1) Positive conductor attached to paper clip; (2) 6- to 8-in. pencil cut in half to expose "lead" graphite; (3) wooden half of pencil glued to cardboard to keep pencil stable; (4) alligator clip clamped to graphite at sharpened end of pencil; (5) clip attached to negative conductor from batteries.

Fig. 38.2, using *braided* wire as the conductor. To expose the graphite (a soft form of carbon) in the pencil, carefully cut away half of the wood. Glue the back side of the pencil to a piece of cardboard to prevent the pencil from rolling when the test for resistance is made. Attach an alligator clip to the free end of the wire conductor that leads to the knife switch. Clamp the alligator clip on the pointed end of the pencil lead (graphite). Attach a paper clip to the free end of the wire leading from the lamp receptacle.

Close the knife switch and rub the paper clip up and down along the graphite. Observe what happens to the intensity of the light emitted from the bulb as the clip approaches the pointed end of the pencil. (The light becomes brighter and brighter.) Why? (As the distance the current flows through the graphite resistor becomes less, the flow of current to the bulb increases.)

After the class has observed the results of the experiment, have the pupils name each of the resistors in the circuit. (Actually every conductor in the circuit offers *some resistance* to the current, but the graphite in the pencil and the tungsten filament in the lamp bulb offer the most.)

Substitute a carbon rod that is the same length as the graphite rod used in the previous experiment and compare the results. Unless the pupils have developed the habit of controlling the variables in an experiment, they may not be concerned about the effect that the difference in the diameters of the graphite and carbon rods has upon the results. Because it is difficult to obtain a carbon rod that is the same diameter as the graphite rod in the pencil, the carbon rod is probably larger in diameter. If this actually is the case, emphasize the importance of qualifying the statement about the results. The carbon rod seems to offer less resistance to the flow of current than the graphite rod.

On a piece of unglazed typewriting paper, outline the four resistors shown in insert A of Fig. 38.2. The dimensions of these resistors are as follows: 1 × ¼ in., 1 × ½ in., 2 × ¼ in., and 2 × ½ in. With the "lead" (graphite) of a soft No. 1 pencil, blacken the four outlined spaces until no white paper shows. Substitute these graphite resistors for the cut-away pencil in the circuit shown in Fig. 38.2. Spread into a fan shape the two disconnected ends of the braided wire. Touch these two wires to opposite ends of each graphite patch. Watch the flashlight bulb. Does it light? (No. A flashlight bulb will not detect any flow of current. The coating of graphite embedded in the paper is so thin, the paper as well as the graphite resists the flow of electricity. Probably the flow of current through these resistors is too small to be detected by a flashlight bulb.)

A meter that measures *a very small current* of electricity must be used with these graphite resistors. The kind of meter used in this experiment is called a *direct current milliammeter* because it reacts to currents that are less than one thousandths of an ampere. An ampere is the measure of the amount of electrons in motion or the flow of current in the circuit.

Have the pupils examine and learn to read a milliammeter like the one shown in insert B of Fig. 38.2. Also locate the negative and positive terminals of the meter before connecting it into a circuit. *Open the knife switch.* Replace the light bulb and receptacle in the circuit shown in Fig. 38.2 with a milliammeter like the one shown in insert B. Before closing the switch be sure the positive and negative terminals on the milliammeter are connected to the correct conductors. Retest the flow of current through the graphite resistors. Record and compare the milliammeter readings. How does the width of these resistors affect the amperage? (Increasing the width of these resistors increases the amperage.) How does the length of these resistors affect the amperage? (Increasing the length decreases the amperage.)

Encourage further experimentation to find the effect of width on the resistance of a resistor to the flow of current. Some of the pupils may want to vary the previous experiment by using carbon rods of different diameters to verify the results that were obtained with the four graphite resistors.

Have several of the pupils use reference books to locate information about rheostats and how they are used. (Rheostats are variable resistors. They are used for many purposes, such as dimming lights in auditoriums and theaters, regulating the speed of electric motors, and so on.) If the school has a rheostat, which causes a variation in the intensity of the lights in the auditorium, make arrangements to have the class observe how it operates. A variation of a rheostat, called a potentiometer, is used to control the volume in radio and television sets.

If the pupils plan to make a transistor radio like the one shown in Fig. 38.10, they should obtain the resistors listed in Table 38.2 and learn more about them.

Carbon resistors use a color code to distinguish one from another. Appoint several pupils to copy Fig. 38.3 and Table 38.1 on large pieces of paper. Practice identifying different resistors with the aid of the figure and table.

When the class has learned how to distinguish one type of fixed resistor from another and how to determine their ohms rating from their color code, they are ready to measure the voltage and amperage of the current in a circuit containing a resistor.

Wire a circuit like the one in Fig. 38.4. Substitute a *pocket-size voltammeter for the milliammeter shown in the figure.* The results will be more nearly accurate if a voltammeter with a

Fig. 38.3 How to identify the different types of carbon resistors used in electronics and use the standard color code to determine their ohms of resistance.

Ohms of Resistance Are Color Coded

Color Codes for Areas 1 and 2 Convert into First Two Figures		*Color Code for Area M Converts to Multiplier (zeros to be added after first two figures)*		*Color Code for Area T converts to Tolerance*	
black	0			gold	±5%
brown	1	brown	0	silver	±10%
red	2	red	00	no color band	±20%
orange	3	orange	000		
yellow	4	yellow	0000		
green	5	green	00000		
blue	6	blue	000000		
violet	7	gold	multiply by 0.1		
gray	8	silver	multiply by 0.01		
white	9				

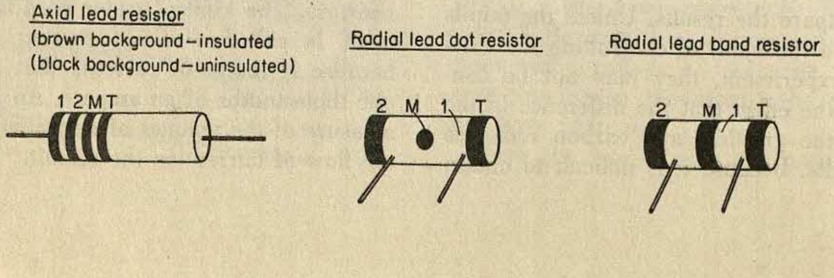

Axial lead resistor
(brown background—insulated
(black background—uninsulated)
1 2 M T
Radial lead dot resistor
2 M 1 T
Radial lead band resistor
2 M 1 T

Table 38.1

EXAMPLES SHOWING HOW TO DECODE THE COLOR MARKINGS OF RESISTORS INTO KILOHMS

Resistors	First Color Figure	Second Color Figure	M Color Marking (multiplier)	T Color Marking (tolerance)	Ohms	Kilohms (K)
1.0 K	brown 1	black 0	red 00	silver ±10%	1,000 ±10%	1 K ±10%
2.7 K	red 2	violet 7	red 00	silver ±10%	2,700 ±10%	2.7 K ±10%
33.0 K	orange 3	orange 3	orange 000	silver ±10%	33,000 ±10%	33 K ±10%
47.0 K	yellow 4	violet 7	orange 000	silver ±10%	47,000 ±10%	47 K ±10%
68.0 K	blue 6	gray 8	orange 000	silver ±10%	68,000 ±10%	68 K ±10%
100.0 K	brown 1	black 0	yellow 0000	silver ±10%	100,000 ±10%	100 K ±10%
200.0 K	red 2	black 0	yellow 0000	silver ±10%	200,000 ±10%	200 K ±10%

Explanation: Notice that the resistors decoded here are the same ones listed in Table 38.2.

dial that is calibrated in tenths of a volt can be obtained.

Ask one of the students to organize a table similar to Table 38.2 on which to record the results of tests the class will make. Starting with the 2.7 K resistor, record the *voltage* in the circuit. Record this result on the table. Check and record the voltage in the circuit with the other resistors in the list.

Table 38.2

RESISTORS AND THE APPROXIMATE VOLTAGE AND AMPERAGE WHEN CONNECTED IN A CIRCUIT

Kilohm Rating of Resistor	Voltage in Volts	Amperage in Milliamperes
2.7 K	2.5	1
33.0 K	2.25	0.65
47.0 K	0.75	0.1
68.0 K	0.5	0.05
100.0 K	0.25	0.02
200.0 K	0.01	0.01

Remove *all resistors* from the circuit in the previous experiment. Substitute a milliammeter, as shown in Fig. 38.4, for the voltammeter. *Start with the 2.7 K resistor.* Read and record the amperage in milliamperes in the circuit for each resistor listed. *Do not test a 1 K resistor.* This 0–1 direct current milliammeter would be damaged by the large amperage flowing through the 1 K resistor. When the class has completed their tests with the resistors and listed their results on their own table, have them compare their results with those given in Table 38.2. Discuss some of the reasons why their results may vary from the ones listed in that table. (Some of the reasons are as follows: (1) the output of the dry cells

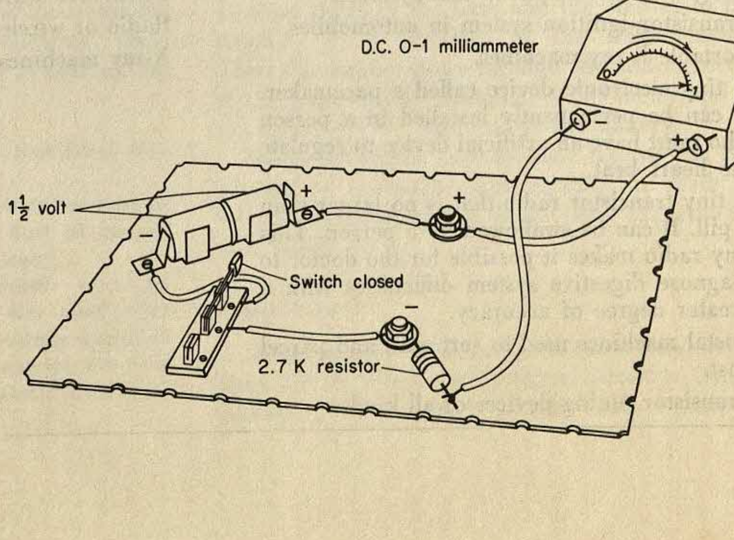


Fig. 38.4 Set-up for checking effects of resistors in a circuit. A 2.7 K resistor (2700 ohms) in a 3-volt circuit limits the flow of current to 1 milliampere (1/1000 of an ampere). A resistance of *less* than 2.7 K cannot be tested with a meter having a range of 0–1 milliamperes. Do *not* test a 1 K resistor in a circuit containing a meter that has this range. A meter with a range of 0–5 milliamperes would be needed for such a test.

may not have been the same; (2) there may have been a difference in the sensitivity of the meters that were used; (3) the skill in reading the measurements may not have been the same; and (4) the meters may have varied in the resistance they offered in the circuit.)

2. Which radio and television components amplify current? How can it be shown that a transistor amplifies the electrical current?

All radio and television sets contain amplifiers that strengthen the weak electromagnetic waves received by antennas. Find out whether the class can name two different kinds of devices (components) that are used to amplify radio and television waves. (Transistors and vacuum tubes.) Many other electronic instruments also use transistors and vacuum tubes. Ask the pupils to name as many of these instruments as they can. See Table 38.3.

Because transistors operate on low voltage (electromotive force) and low amperage (small current), *they are safe for children to use in experiments*. For this reason, the experiments in this inquiry and in several of the succeeding ones deal with circuits that contain a transistor. The materials used in the experiments can be obtained from radio service shops or from the science supply room. The circuits can be wired on the same pegboard used in Chap. 37. The three experiments developed in this inquiry will help the children personally to observe that a transistor does control and amplify current.

Agree upon some rules that the class should follow when they are working on circuits con-

Table 38.3

ELECTRICAL DEVICES WHICH USE EITHER TRANSISTORS OR VACUUM TUBES TO AMPLIFY WEAK ELECTROMAGNETIC WAVES

Devices that Contain Transistors	Devices that Contain Vacuum Tube Amplifiers
Small radio receiving sets.	Large radio sending and receiving sets.
Small television receiving sets.	Large television sending and receiving sets.
All airborne magnetic devices that store and transmit recorded signals.	Large electronic computers.
Small electronic computers (portable).	Radar sending and receiving sets.
Transistor hearing aids.	Oscilloscope—has a fluorescent screen like a television receiving set. The screen becomes luminous when a stream of electrons strike it. The oscilloscope can be used for many different purposes. It can graph both sound and radio waves in a visible form.
Telemetry devices—used to record readings from instruments at a distance and to record and plot distances. These devices are used in satellite tracking and for military purposes.	Telemetric devices.
Long distance telephone dial systems.	Radio or wireless telegraphy.
Transistor ignition system in automobiles.	X-ray machines.
Portable X-ray machines.	
A tiny electronic device called a pacemaker. It can be permanently installed in a person who must have an artificial device to regulate the heart beat.	
A tiny transistor radio that is no larger than a pill. It can be swallowed by a person. This tiny radio makes it possible for the doctor to diagnose digestive system difficulties with a greater degree of accuracy.	
Postal machines used to sort mail and parcel post.	
Transistor tuning devices of all kinds.	

taining a transistor and a meter. Some of these precautions should be included in their list:

1. **Always work *from a diagram that shows how each component should be connected* in the circuit.**
2. **Check the conductor wires at each connection to make certain that they make a good contact.**
3. **Leave the switch in the *off* position until all connections have been made and checked.**
4. **Always pull the blade of the knife switch to the *off* position when finished with the experimentation.**

Ask one of the pupils to draw a large copy of Fig. 38.5 and display it where it can be seen by the class. In the diagram, the 2N107 transistor is the only component with which the children may not be familiar. Examine the transistor before wiring it into the circuit. Note that there are three small wires protruding from the bottom of the transistor. Each of these wires is attached to the small fused crystal that is inside the transistor. Actually this fused crystal contains three sections, to each of which a wire is connected.

Use a ruler to measure the distance between the three wires. In Figs. 38.5 and 38.7 they are labelled (*e*), emitter; (*b*), base; and (*c*), collector. The distance between wires (*b*) and (*e*) is less than the distance between wires (*b*) and (*c*). There also may be either an identifying mark, or a protuberance near wire (*c*). Observe that the collector wire (*c*) and the base wire (*b*) *are both connected to the negative (–) terminal of the battery* and that the emitter wire (*e*) is connected to the positive (+) terminal of the battery. Note carefully how the milliammeter is connected.

The directions, observations, and questions for discussion suggested in the following three experiments should help the class to develop the following understandings:

1. **Resistors regulate the current that flows into the base of the transistor.**
2. **A high resistance in the circuit to the base of the transistor decreases the flow of current more than a low resistance does.**
3. **The current through the transistor from the collector to the emitter *is very small when there is no base current.* When voltage is applied in *both the base and collector circuits,* the flow of current through the base controls the current through the collector circuit.**

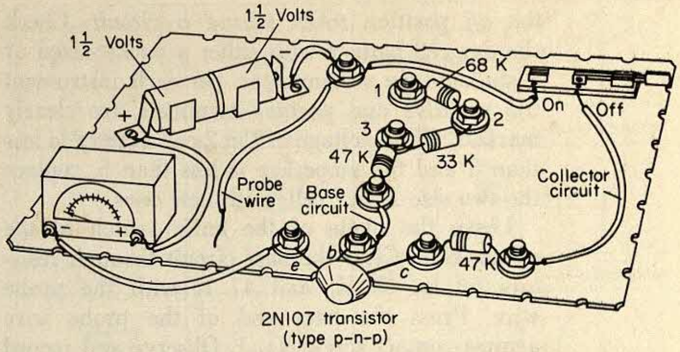


Fig. 38.5 Set-up for measuring current through transistor circuits.

4. **Transistors amplify current.**
5. **Amplification is controlled by the current (amperage) that flows into the base transistor.**

Help the class to trace the two circuits in Fig. 38.5 in which electrons can flow. These two circuits are called (1) the collector circuit and (2) the base circuit.

Collector Circuit. See Fig. 38.5. The current in the collector circuit flows through the machine screw, through the throw switch to the 4.7 K resistor into the collector wire (*c*) of the transistor. From the collector, the current travels through the base (*b*) into the emitter (*e*) to the negative (–) terminal of the milliammeter, and through the milliammeter to the positive (+) terminal of the battery.

Base Circuit. See Fig. 38.5. The current in the base circuit flows through the machine screw, through the tester probe wire and the three resistors into the base wire (*b*) of the transistor. It flows through the base and the emitter to the negative (–) terminal of the milliammeter. Then the current flows through the milliammeter to the positive (+) terminal of the meter and to the positive (+) terminal of the battery.

When the pupils have finished tracing the two circuits on the large diagram, they are ready to set up the circuit and to do the three experiments that follow.

Experiment 1

Measure and Record the Current That Flows in the Base Circuit When the Collector Circuit Is Open. Always push the blade of the knife switch to the *off* position *when wiring a circuit.* Check the dry cell battery with either a pocket-sized or a student-type voltammeter. On each instrument the negative and positive terminals are clearly marked. If the voltage of the 2-cell battery is less than 3 and the amperage is less than 5, replace the two size D dry cells with new ones.

Leave the blade of the knife switch in the *off* position. Close the base circuit through resistors 68 K, 33 K, and 47 K with the probe wire. Press the bare end of the probe wire against contact screw No. 1. Observe and record the meter reading. Move the probe wire to contact screw No. 2. Observe and record the meter reading again. Move the probe wire to No. 3. Again observe and record the meter reading. What happens to the current as the probe wire is moved from screw No. 1 to screw No. 2, and finally to screw No. 3? (The current increases as resistors are cut out of the circuit.) What causes the current to increase? (The resistance to the flow of current is decreased by cutting out first one and then two of the resistors from the circuit.)

Experiment 2

Measure and Record the Current That Flows in the Collector Circuit When the Base Circuit Is Open. Be sure that the probe wire does not close the circuit to the base of the transistor. *The base circuit must remain open during this experiment.* Push the blade of the knife switch to the *on* position. Measure and record the current that flows in the collector circuit. (The flow will be *very small.* It may be too small to read on the meter. However, the pupils should be able to see that the indicator needle does flicker.)

Compare the amount of current that flows through the base circuit when it contains *only the 47 K resistor* with the amount of current through the collector circuit, which also contains a *47 K resistor.* Through which of the two separate circuits did more current flow, the base or the collector circuit? (The base circuit.) Apply the concept the pupils have formed from their experience with resistors in Experiment 1. Find out whether they can guess why less current flows in the collector circuit. (The transistor *must resist* the flow of current from the collector to the emitter *more than it resists* the flow of current from the base to the emitter.)

Experiment 3

Measure and Record the Amplification That Occurs When Both the Base and the Collector Circuits Are Closed. Push the blade of the knife switch to the *on* position. Touch the probe wire to machine screw No. 1 and record the meter reading. Move the probe wire to machine screw No. 2 and record the reading. Touch the probe wire to machine screw No. 3 and record the meter reading. Compare these three readings with the three readings recorded in Experiment 1. How does each of the three readings in Experiment 3 differ from the three readings recorded in Experiment 1? (Each is larger.) In each case, approximately *how many times larger* are they? (They should be approximately five times larger.) When current is applied *to both the base and collector circuits* of the transistor, what happens? (The current *is made larger or amplified.*) What would happen if a weak electromagnetic wave signal were fed into the base of this transistor when both the base and collector circuits are closed? (The electromagnetic waves—radio signal—would be amplified.)

It would be helpful to the class if a few students who are interested in mathematics would make bar graphs of the meter readings recorded in Experiments 1 and 3. These graphs should show two things: (1) *amplification,* and also (2) that every variation in the base current causes *the same variation* in the amplified current.

3. Why are symbols used in diagrams of electrical circuits?

Children who are interested in the building of transistor radio sending and receiving sets will find it very helpful to learn how to interpret schematics (diagrams containing symbols). Figure 38.6 contains a list of symbols that are commonly used in schematics of electronic circuits. Figure 38.7 shows the schematics for a p-n-p type transistor. Ask the pupils to copy these figures. Discuss the reasons why symbols are better to use than line drawings with labels. The reasons will be seen readily if the circuit the children wired in Fig. 38.5 and the diagram they made of it are compared with Fig. 38.8. Point out the simplicity of a schematic and the ease with which the flow of current can be traced on it. Emphasize the skill and larger amount of time that is required to make labeled drawings.

Encourage the pupils to think of other reasons why symbols are better to use than line drawings with labels. (Some of the reasons are as follows: (1) schematics are cheaper to reproduce for publication; (2) the symbols are used internationally; and (3) publications containing schematics require less time to translate from one language to another.)

Ask questions similar to the following to help the pupils interpret this kind of diagram:

1. What do the symbols 1–9 in Fig. 38.8 represent? (See explanation under the diagram.)
2. How can the difference between the negative and the positive electrodes in the symbol used for a battery be distinguished? (The positive electrode is represented by a longer and thinner line than the negative electrode.)
3. Is the circuit in the schematic opened or closed at the knife switch? (It is closed because the arrow representing the blade of the switch is in contact with the wire conductors in the circuit.)
4. What symbol is used to show that wires are joined? (+)
5. What shows that the current from the negative electrode of the battery enters the negative side of the meter? (This question can be answered by tracing the flow of electrons from the negative terminal of the battery. See the arrows in Fig. 38.8. The arrows trace the flow of electricity.)
6. In how many circuits can the current flow in Fig. 38.8? (When the probe wire closes the base circuit, current can flow in two circuits.)

Ask each pupil to make his own schematic of the circuit shown in Fig. 38.5. Encourage identification of each of the symbols without looking at the symbol chart. When the pupils have finished, let each pupil check his schematic with Fig. 38.8 and correct any errors that he may have made. Ask a few of the pupils to trace for the class the direction of the current flow in *their schematics*. Then ask each pupil to do the same thing by drawing arrows on his own schematic.

Emphasize during the discussion period how important it is to understand why symbols are used and what the symbols represent. All forms of communication would be impossible without

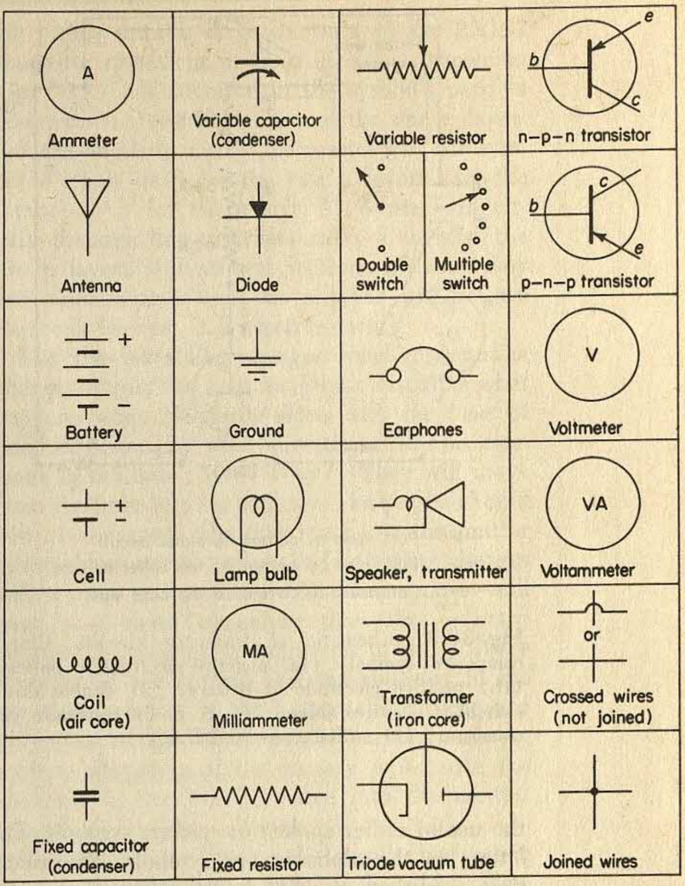
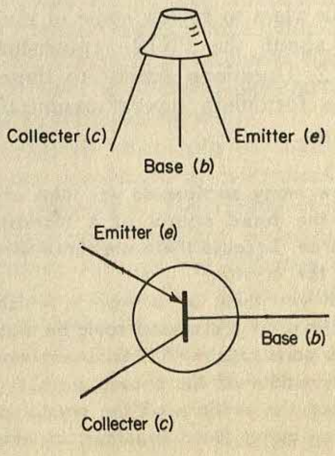


Fig. 38.6 Common symbols used in diagrams of radio and television circuits.

Fig. 38.7 The relationship between a p-n-p transistor and its symbol. In a circuit a wire conductor would be attached to each of the transistor's three terminals.



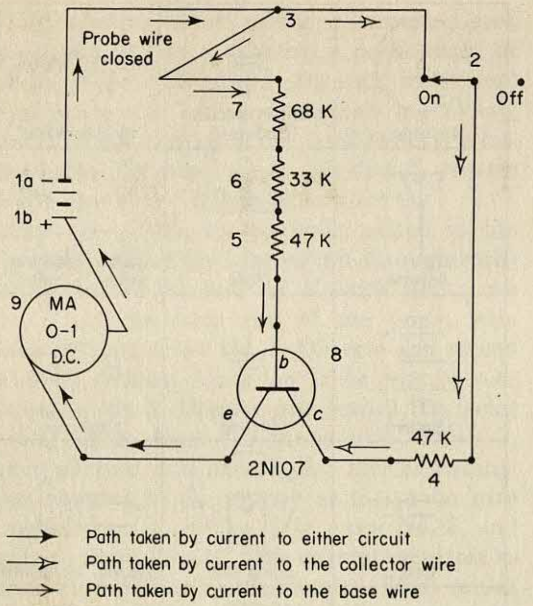

Probe wire
closed
3
2
On
Off
7
68 K
6
33 K
5
47 K
1a
1b
9
MA
0-1
D.C.
b
8
e
c
47 K
2N107
4
Path taken by current to either circuit
Path taken by current to the collector wire
Path taken by current to the base wire

Fig. 38.8 Schematic of transistor circuits. Circuit component symbols: (1a) negative electrode of battery; (1b) positive electrode of battery; (2) double throw switch; (3) wires joined; (4, 5, 6, 7) resistors; (8) transistor; (9) milliammeter 0–1 D.C.

the use of either spoken or written symbols. The letters in the alphabet are symbols. Multiplication, addition, division, and subtraction signs and numbers are also symbols.

4. How is a transistor made? How does a transistor control and amplify current?

Ask the class to review some of the facts they learned about the 2N107 transistor used in Inquiry 2. Questions similar to these will help pupils to formulate several *assumptions* about transistors:

1. How many sections do you think are contained in the fused crystal of a transistor? Why? (Three, because there are three wires attached to the crystal.)
2. Can you think of a way in which the *three sections* of the crystal could be made *by fusing two parts together*? (Yes. Insert one part into the middle of the second part.)
3. Since the sections of the crystal are referred to as being fused together, in which state of matter would the fusion have been made—liquid, solid, or gas? (In the liquid, or molten state, some substances will fuse together.)
4. Why is the name *solid state* used to distinguish transistor radio and television sets from sets that contain vacuum tubes? (The electrons flow through a solid—the crystal—in a set that contains transistors. In sets that contain vacuum tubes, the electrons flow through a vacuum.)
5. Define the word *transistor*. (A transistor is a resistor that allows some current to pass through it.)

Give the students an opportunity to state additional information that they would like to find out about transistors. Help them to locate information that will enable them to check upon the accuracy of their *assumptions* and to find the *additional facts* in which they are interested. Encyclopedias and current science bulletins will be their best sources of information. Some students may also like to look for information in elementary physics books. From these sources, information similar to the following can be obtained.

The substances from which transistor crystals are made are called semiconductors. Semiconductors offer *less resistance* to the movement of electrons than nonconductors. However, semiconductors offer *more resistance* to the movement of electrons than do such conductors as metals, metallic salts, and acids.

Tiny crystals of semiconductors can be used to *control*, or regulate, the quantity of current that flows in a circuit. They can also be used to *amplify* current. In some circuits, these tiny crystals have replaced the larger vacuum tubes. The use of semiconductors has opened a new era in the field of miniaturized electronic components.

There are a number of elements, such as silicon and germanium, that can be made into semiconductors by alloying (mixing) them with different kinds of elements. Germanium is one of the elements that is commonly used. *Germanium will not conduct electricity when it is pure.* It can, however, be changed into a semiconductor by alloying it with certain specific elements. The kind of element with which it is alloyed depends upon the type of crystal that is desired.

There are two general types of crystals. If either *arsenic* or *antimony* is alloyed with germanium, the crystal formed will *release electrons*

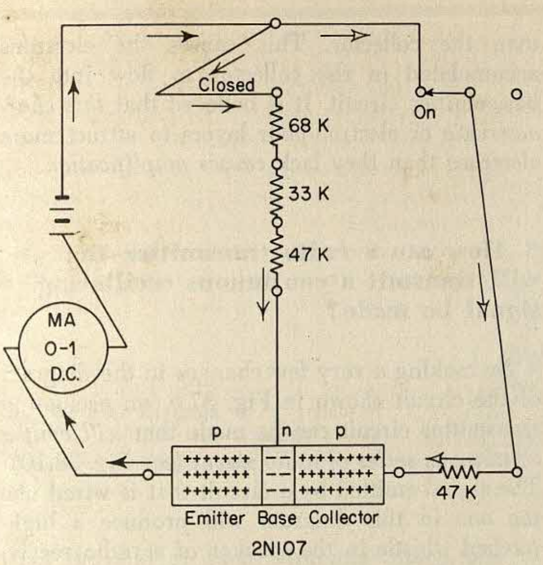


Fig. 38.9 Enlarged representation showing flow of current through the fused layers of a p-n-p type transistor.

(−) when a small electromotive force is applied to it. This type of crystal is called an "n" type. Semiconductors that release electrons are referred to as being *electron-rich,* or having a surplus of electrons.

If either *aluminum, boron, gallium,* or *indium* is alloyed with germanium, the crystal formed will *attract electrons* when a small electromotive force is applied to it. A semiconductor that attracts electrons is called a "p" type crystal. Semiconductors that attract electrons are said to be *electron-poor,* having a deficiency of electrons. The symbols (−) and (+) are used to distinguish electron-rich (−) from electron-poor (+) semiconductors. (See Fig. 38.9.)

Two types of transistors are commonly made from the electron-rich (−) and electron-poor (+) semiconductor crystals. They are the p-n-p and the n-p-n type transistors. The p-n-p type transistor crystal is made by fusing a thin slice of an n crystal (electron-rich) into the center of a p type crystal (electron-poor). The n-p-n transistor crystal is made by fusing a thin slice of a p type crystal (electron-poor) into the center of an n type (electron-rich) crystal. The 2N107 transistor used in Inquiry 2 is a p-n-p type transistor (see Fig. 38.9).

How do n and p type layers in a p-n-p crystal control and amplify the current? Have one of the pupils draw a large diagram of the 2N107 transistor crystal in a *closed circuit* as shown in Fig. 38.9. Call attention to the symbols used to designate the two p layers and the one n layer. Ask the pupils to restate the reason why the symbol (+) is used for the two p layers and the symbol (−) for the n layer? (When both circuits through this transistor carry a current, the two p layers will attract electrons because they are electron-poor and the n layer will release electrons because it is electron-rich.)

Use the law *"like charges repel and unlike charges attract"* to help the pupils visualize what happens when electricity flows *into the base* of this transistor. In what direction will the electrons in the base move? Why? (They will move from the base into the emitter. The pupils should know two reasons why they move into the emitter rather than into the collector: (1) Unlike charges will attract each other; (2) The *emitter* will have a stronger attraction than the collector because the emitter is connected to the *positive terminal of the battery* and the collector to the negative terminal of the battery. The *combined attraction* of the electron-poor emitter and the positive electrode of the battery will cause the electrons in the base to move into the emitter instead of into the collector.)

Recall the experiences the pupils had when they did Experiments 1 and 2 in Fig. 38.5. How did the record of the amount of current through the 47 K resistor in the base circuit of the transistor (experiment 1) compare with the record of the amount of current through the 47 K resistor in the collector circuit of the transistor (experiment 2)? (There was more current through the base circuit than through the collector circuit. Because both circuits contained 47 K resistors, the transistor must have *resisted the flow of electrons in the collector circuit more* than it did in the base circuit.)

What happened when both the base and collector circuits were closed in experiment 3? (The current was amplified. The results of the three experiments indicate that the resistance to the flow of current through the collector circuit *is decreased when current flows in the base circuit.*)

Why is there *greater resistance* between the collector and the base *when the base circuit is open?* (The electrons from the battery that are attracted into the collector do not move readily into the adjoining base layer because the electron-rich base layer repels most of them. Like charges of electricity repel each other. A few electrons do move across the three layers of the crystal from the collector to the emitter. The movement of these few electrons causes a *very small current* to flow in the collector circuit when the base circuit is open.

Why is the *resistance less* between the base and the emitter than it is between the collector and the base? Observe that the emitter is connected by a conductor to the positive terminal of the battery and that the base is connected to the negative terminal. (Two forces—repulsion and attraction—reduce the resistance between the base and the emitter. The electrons from the battery *repel* the electrons in the electron-rich base layer into the emitter (like charges of electricity repel each other). The repelled electrons in the electron-rich base are also *attracted* by the emitter and the positive electrode of the battery, both of which are electron-poor. As fast as the electrons move from the base to the emitter, more electrons from the negative electrode of the battery enter the base.)

In Inquiry 2, the pupils learned that amplification occurred when electrons flowed into *both the base and the collector* sections of the transistor. Since amplification occurs *only when the base emitter circuit is closed,* it is reasonable to *assume* that this flow of current causes the amplification. It is also reasonable to *assume* that the flow of electrons through the base-emitter circuit decreases the resistance between the collector and the base. Any decrease in the resistance between the collector and the base would cause an increase in the flow of current through the collector-base-emitter circuit. How the base-emitter circuit causes amplification is unknown. However, there is a theory that describes the changes that are believed to cause amplification.

In a p-n-p type transistor, there are two electron-poor semiconductors (emitter and collector) and one electron-rich semiconductor (base). According to the theory, it is a characteristic of electron-poor semiconductors to attract *more electrons than they lack.*

The electron-poor emitter attracts electrons from the base and the electron-poor collector attracts electrons from the negative electrode of the battery. (See Fig. 38.9).

When electrons flood from the base to the emitter, the base becomes less negatively charged than the collector. This causes the electrons accumulated in the collector to flow into the base-emitter circuit. It is believed that *this characteristic* of electron-poor layers to attract more electrons than they lack *causes amplification.*

5. How can a radio transmitter that will transmit a continuous oscillating signal be made?

By making a very few changes in the diagram of the circuit shown in Fig. 37.6, an oscillating transmitter circuit can be made that *will emit a continuous series of radio waves* (see Fig. 38.10). The signal emitted by a circuit that is wired like the one in this diagram will produce a high-pitched whistle in the speaker of a radio receiving set, if the radio is tuned to the proper frequency.

Most of the components needed for wiring a continuous, oscillating transmitter circuit have been used in previous inquiries. The two fixed condensers (capacitors), because of their exterior appearance and shape, *will seem to be new* to the pupils. Explain that these capacitors are similar to small Leyden jars and have a similar capacity for storing charges of electricity. (See Fig. 36.10.) Machine screws of different lengths ($\frac{1}{2}$ inch to 1 inch) and extra nuts will make it easier to connect the components into the circuit. The longer screws should be used for contact points 2, 4, 5, 6, 7, and 9. Use additional nuts to connect the extra wires to these contact points. Remind the pupils to keep the *knife switch open* until they have completed wiring the circuit and checked it with the diagram in Fig. 38.10.

The *same coil and variable condenser* that were made by the class for the experiment described in Fig. 37.6 are used in this experiment. Before mounting the coil, *add coil B.* Make coil B by winding 8 turns of bell wire (No. 18) on *one end* of the cardboard tube. These eight turns of wire should be wound *in the same direction* around the cardboard tube as the turns of wire in coil A. Start this second winding about 5 inches from the end of the wire and wrap part of the turns *on top of the last few turns of coil A.* (See Fig. 38.10.)

After completing the eight turns in coil B, twist the two wires together to prevent their unwinding. Remove 3/4 of an inch of insulation

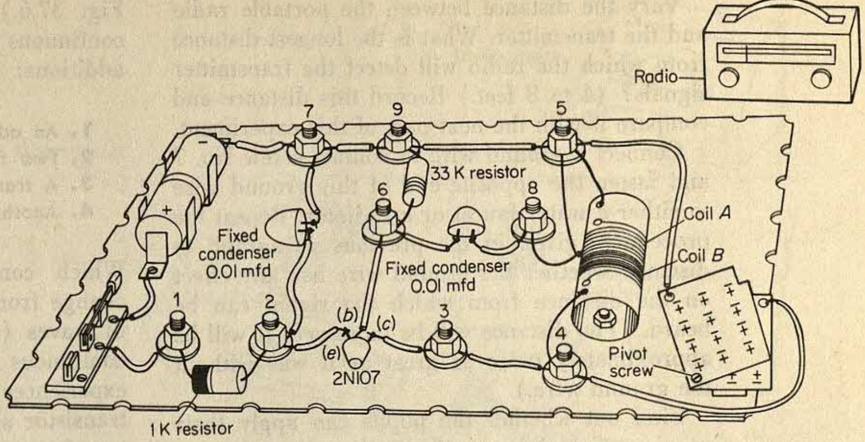


Fig. 38.10 Diagram of a transistor radio circuit that will transmit a continuous oscillating signal.

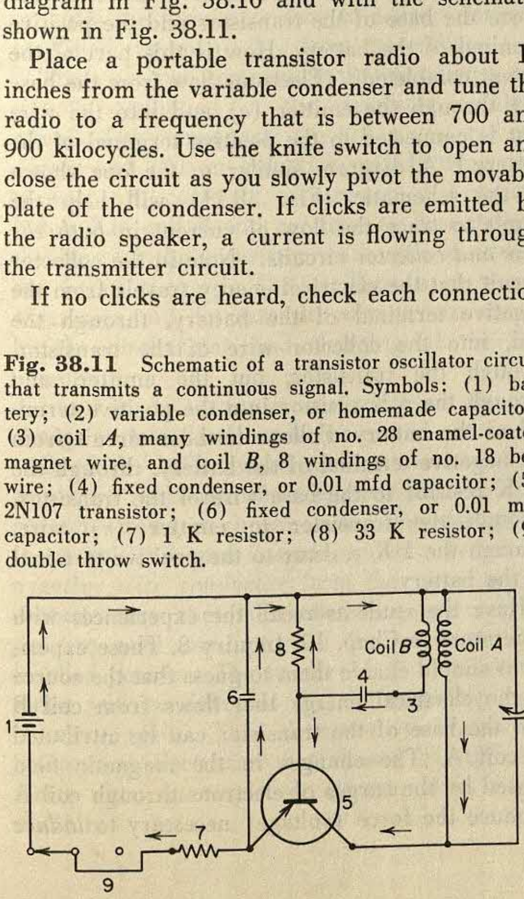
from the end of each wire and attach one to machine screw 5 and the other to 8 as shown in the diagram.

Before closing the switch in the transmitter circuit, the pupils should check it with the diagram in Fig. 38.10 and with the schematic shown in Fig. 38.11.

Place a portable transistor radio about 12 inches from the variable condenser and tune the radio to a frequency that is between 700 and 900 kilocycles. Use the knife switch to open and close the circuit as you slowly pivot the movable plate of the condenser. If clicks are emitted by the radio speaker, a current is flowing through the transmitter circuit.

If no clicks are heard, check each connection to make certain that there is a good contact between the components and the wire conductors. Close the knife switch and listen for a shrill whistling sound as the movable plate of the variable condenser is pivoted. If, after repeating this procedure several times, this whistling sound is not heard, reverse the connections of the two wires on coil B at machine screws 5 and 8 and try again. This time the whistle (radio signal) should be heard. If not, the variable condenser plates are too far apart. Tighten the pivot screw that holds the two condenser plates together. The two plates should be as close together as possible and still allow the movable plate to pivot. This time the radio transmitter signal (whistle) will be heard.

Fig. 38.11 Schematic of a transistor oscillator circuit that transmits a continuous signal. Symbols: (1) battery; (2) variable condenser, or homemade capacitor; (3) coil *A*, many windings of no. 28 enamel-coated magnet wire, and coil *B*, 8 windings of no. 18 bell wire; (4) fixed condenser, or 0.01 mfd capacitor; (5) 2N107 transistor; (6) fixed condenser, or 0.01 mfd capacitor; (7) 1 K resistor; (8) 33 K resistor; (9) double throw switch.



To assure the children that the sound being emitted by the radio speaker is caused by the radio transmitter, open the switch. The whistling will stop. Open and close the switch several times. Each time the circuit is opened, the signal emitted by the radio will stop.

Find out how many different wave frequencies can be emitted by the transmitter circuit. This can be done by gradually decreasing the overlap between the two plates. Compare the difference between the overlap when the radio is tuned to a lower frequency and when it is tuned to a higher frequency. (There will be more overlap when the transmitter emits low frequency waves than there will be when it emits high frequency waves.) There should be several frequencies between 500 and 1500 kilocycles, at which the transistor radio will detect the signals emitted by the transmitter.

Vary the distance between the portable radio and the transmitter. What is the longest distance from which the radio will detect the transmitter signals? (4 to 8 feet.) Record this distance and compare it with the next part of this experiment.

Connect a ground wire to contact screw No. 7 and fasten the opposite end of this ground wire to either a water faucet or a radiator. Repeat the procedures given in the previous paragraph to discover whether the ground wire has any effect on the distance from which the signal can be heard. (The distance will be increased. It will be approximately twice as great as it was without the ground wire.)

Find out whether the pupils can apply their previous experiences with condensers and resistors to the solution of this problem. Questions similar to the following ones can be used:

1. Why is the 1 K resistor connected in the circuit between the positive terminal of the battery (screw 1) and the negative terminal of the battery (screw 2)? (To control the amount of current there is in the circuit.)
2. Why are two fixed condensers connected in the circuit? (They are there to store electrical charges. When the fixed condensers and the variable condenser are fully charged, the electricity which they have stored will be released —discharged—and will increase the flow of current in the circuit.)
3. How is a fixed condenser different from a variable condenser? (The electrical charge stored by a fixed condenser is limited by the size of its plates and this charge cannot be varied because a fixed condenser does not have a movable plate.)
4. Which resistor, the 1 K or the 33 K, holds back more current? (The 33 K resistor holds back more current. See Table 38.2.)
5. Why is the 33 K resistor connected between the base (b) of the transistor and the negative terminal of the battery? (The current flowing into the base of the transistor should be smaller then the current that flows into the collector of the transistor. See Inquiry 2.)

Guess why continuous radio waves are emitted by this transmitter. The children will make more educated guesses if they compare their diagrams of the transmitter circuit with the diagram of the transmitter that emitted only a sharp click each time the circuit was opened and closed. (See Fig. 37.6.) Observe that the diagram of the continuous signal circuit contains the following additions:

1. An additional resistor;
2. Two fixed condensers;
3. A transistor;
4. Another coil of wire consisting of eight turns.

Which components in the circuit cause the change from a transmitter that emits one series of waves (a click) to a transmitter that emits continuous radio waves? The pupils' previous experiences with resistors, condensers, and a transistor should enable them to guess that the transistor and the second coil of wire may be the cause.

Observe that one of the ends of the wire that makes the coil of eight windings is connected to the base of the transistor and that the other end of this coil wire is connected to the wire conductor from the negative terminal of the battery. Also note that there is no direct connection between the base of the transistor and the positive terminal of the battery. How is this part of the circuit completed? (Electrons flow from the base (*b*) through the emitter (*e*) and into the wire that is connected to the positive terminal of the battery.) A diagram similar to the one shown in the schematic (Fig. 38.11) will help the pupils to trace the flow of current in *both the base and collector* circuits. Note in the collector circuit that the electrical energy travels from the negative terminal of the battery, through the coil, into the collector wire of the transistor, through the transistor, out the emitter, and through the 1 K resistor into the positive terminal of the battery. Follow the base circuit from the negative terminal of the battery, through the 33 K resistor to the base wire of the transistor, through the transistor to emitter (*e*) wire, through the 1 K resistor to the positive terminal of the battery.

Have the students recall the experiences with generators in Chap. 19, Inquiry 8. These experiences should enable them to guess that the source of the electrical energy that flows from coil B into the base of the transistor can be attributed to coil A. The changes in the magnetic field caused by the surges of electrons through coil A produce the force (voltage) necessary to *induce*

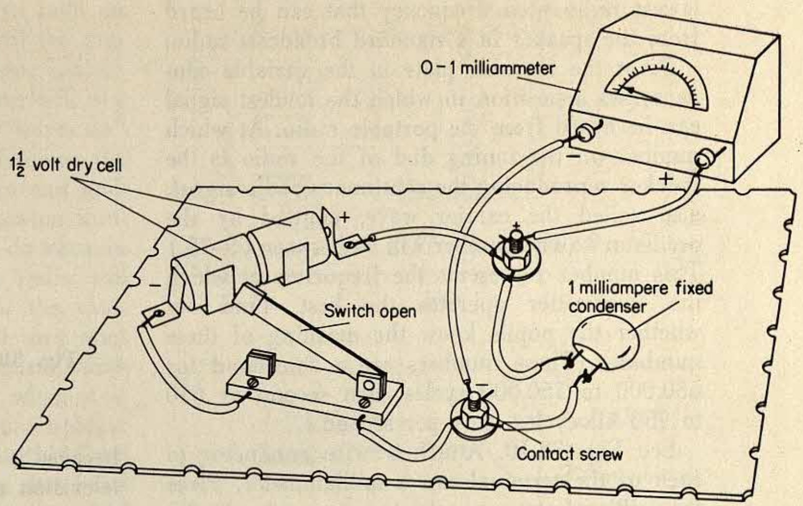


Fig. 38.12 Set-up for discovering if a fixed condenser stores and discharges electrical energy.

a small current of electricity in coil B. This small current flows into the base of the transistor. In Inquiry 4, the pupils learned that a small current flowing through the base of the transistor provides the force necessary to cause a large or amplified current to flow from the emitter.

There are two components that produce a *continuous* oscillation in the transistor oscillator circuit. The components are (1) a variable condenser and (2) an induction coil. If these components are correctly constructed, the current induced in coil B will continue to flow through the base of the transistor while the condensers are being charged. The oscillations or surges (increases and decreases in current) are caused by the discharging and charging of the condensers.

See Fig. 38.12 for a way to detect the discharge from a fixed condenser.

Open the knife switch and connect the fixed condenser between the negative and positive contact screws as shown in the diagram. Close the switch and open it again, quickly. *Touch* the *negative wire conductor* from the meter to the contact screw that is labelled *negative* and the *positive wire conductor* to the contact screw labelled *positive.* The needle on the dial of the meter will be deflected slightly and drop back to zero again. This deflection indicates the *amount of electricity* that flowed through the meter when the condenser discharged its stored electrons.

Lift the two wires away from the contact screws and touch them to the same contact screws again. Why did the meter not register any flow of electricity? (The fixed condenser discharged its electrical energy the first time that the two wire conductors from the meter touched the contact screws. The fixed condenser must be recharged and discharged before any current will flow through the meter again.) Repeat this procedure several times to make sure that the same results will be obtained. (They will be.)

Compare the intensity of the current flow registered by the meter with the energy capacity listed on the condenser. (The capacity listed on the condenser is 1 milliampere. The meter reading will be less than 1 milliampere.) Why is the meter reading less than the capacity of the condenser? (Each conductor and component in the circuit converts some of the electrical energy into heat energy. The greatest loss of energy occurs in the meter.)

The pupils will develop a greater appreciation for the many thousands of oscillations that produce the steady shrill whistle in this oscillating circuit, if they realize how rapidly a condenser can be charged and discharged. Ask one child to open and close the switch in the circuit as rapidly as he can, and have the class count the number of times the circuit was *closed* in one second. The condensers in the continuous signal oscillator circuit must be charged and discharged at least 550,000 times a second to produce the lowest radio wave frequency that can be heard from the speaker in a standard broadcast radio.

Pivot the movable plate in the variable condenser to a position in which the loudest signal can be heard from the portable radio. At which number on the tuning dial of the radio is the speaker reproducing the continuous radio signal, also called the carrier wave, emitted by the oscillator? (The number will be between 65–75.) This number represents the frequency at which the transmitter operates the best. Find out whether the pupils know the meaning of these numbers. (These numbers are a shorthand for 650,000 to 750,000 cycles each second or 650 to 750 kilocycles—kc—per second.)

See Fig. 38.10. Attach a wire conductor to each of the terminals on a milliammeter. Place the milliammeter *near* the transistor circuit. *Do not connect the meter in the circuit.* Measure the oscillatory current flowing through both the base and the collector. To measure the base current flow into the transistor, *press* the bare end of the wire conductor from the negative terminal of the milliammeter against contact screw No. 6 (base) and the positive conductor from the meter against contact screw No. 2 (emitter). Observe the deflection of the needle on the dial of the meter. The collector current flow can be measured by *touching* the negative wire conductor from the milliammeter to contact screw No. 3 (collector) and touching contact screw No. 2 (emitter) with the positive conductor from the meter. As soon as the wires touch the contact screws, note the meter reading and *immediately remove* the meter wires. The amplified current flowing from the emitter could be large enough to damage the meter.

Help the pupils summarize the results of their experiences with the continuous signal transmitter. Also, provide opportunities for them to use the new vocabulary that has been developed during their experiences in solving this inquiry.

6. How is a vacuum tube made? How does a vacuum tube amplify current? How are vacuum tubes made to oscillate? What are some of the advantages and disadvantages of transistors and vacuum tubes?

The simplest kind of vacuum tube, the triode, is not readily available for pupils to study because it has been replaced by most radio and television manufacturers with the more efficient tube called the pentode.

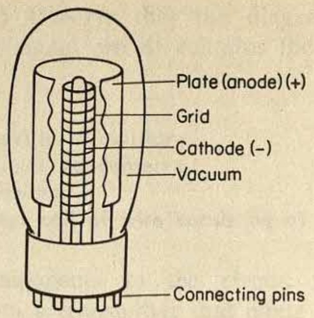


Fig. 38.13 A triode vacuum tube amplifier.

As the names of these two tubes imply, the triode is composed of three electrodes. A triode tube contains a *cathode*, an *anode*, and a *grid*. The cathode is the negative electrode. The anode called the *plate* is the positive electrode. The grid placed between the cathode and the anode controls the movement of electrons from the cathode to the anode. Figure 38.13 shows a triode vacuum tube.

A pentode vacuum tube contains a cathode, an anode, and *three grids*. The difference between a pentode and a triode tube is only a difference in the number of grids.

Burned out pentodes are readily available from radio and television service shops. These shops may also have a *burned out* triode tube, which pupils can examine. Examine both tubes and try to identify their parts. The grid, or grids, will be located between the cathode and the plate. Grids are composed of either a coil of wire or a sievelike metallic plate. A *burned out* tube will have tiny specks and patches of a black substance on the inside of the glass. These specks and the black substance may be either a barium or a strontium compound, depending upon the kind of material with which the cathode was coated. If tiny specks of a substance that looks like silver are visible on the inside of the glass, these particles may be globules of mercury that vaporized (boiled off) when the tube was in use. The inside of some kinds of vacuum tubes is partially coated with mercury.

Obtain two radios—one with vacuum tubes and the other with transistors. Tune both radios to the same broadcasting station. Turn both on *at the same time.* On which radio will the program be heard first? (On the transistor radio.) Why? Students who know the reason will say that the tubes in the radio have to "warm up" before the program can be heard. Remove the back cover of the vacuum tube radio and look at the tubes. A dull red light will be seen shining through some of the tubes. Why do vacuum tubes have to be heated before the radio will work? (In Inquiry 3 of Chap. 36, the class learned that when metals are heated they emit millions of electrons.) Let the pupils guess which part of the tube will emit electrons when it is heated. (The cathode will emit electrons because it is the negative electrode. The current that flows into the cathode, or into the filament that heats the cathode, provides both the heat energy and voltage that are necessary to emit electrons from the heated cathode.) What happens to these free electrons? [They are attracted to the positive anode (plate). They cross the vacuum between the cathode and the plate.] How does the vacuum in the tube enable the electrons to move from the cathode to the plate? (The vacuum does this in two ways: (1) The electrons can move from the cathode to the plate more readily in reduced pressure; and (2) when moving through a vacuum, electrons *do not lose energy.* If electrons were to move past air molecules in a tube, there would be friction between them. The friction would convert some of the electrical energy of the moving electrons to heat energy. This would be a loss of electrical energy.)

How Do Vacuum Tubes Amplify Current? If the following clues are given, pupils should be able to compare the amplification that takes place in a vacuum tube with the amplification that occurs in a transistor. [See Fig. 38.14 (b) and (c).]

1. **When *the grid becomes more positive, the positive plate (anode) attracts and collects more free electrons* from the cathode. When *the grid becomes less positive, the positive plate* (anode) *attracts and collects fewer electrons* from the cathode. The grid regulates and controls the flow of electrons to the plate.**
2. **A vacuum tube is similar to a transistor. In a vacuum tube the cathode and anode (plate) can be compared to the collector and the emitter in a p-n-p junction transistor. The grid regulates and controls the flow of current through the tube in much the same way that the base current of the transistor regulates and controls the flow of current through a transistor.**

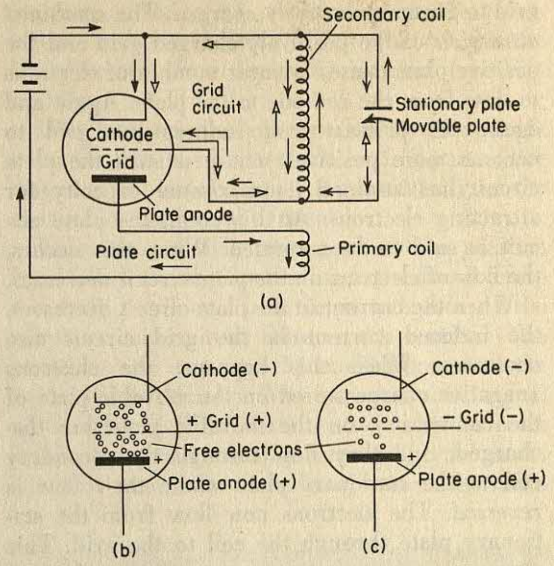


Fig. 38.14 (a) Circuit showing how the flow of current to the grid of a triode vacuum tube oscillates. Arrow key: ——► Flow of electrons in plate circuit containing a primary coil. ——▻ Induced current in the circuit containing a secondary coil flows away from the grid. ——> Electrons stored on the moveable plate of the condenser discharge through the secondary coil to the stationary plate where their flow is reversed; the result is a reverse flow through the secondary coil back to the grid. The flow of electrons from the cathode to the plate thus oscillates—increases and decreases—in the intensity of its electrical charge, causing the transmission of radio waves. In (b) more electrons are attracted to the plate (anode) when the grid has a positive charge; in (c) fewer electrons are attracted to the plate when the grid has a negative charge.

Discuss why more than one transistor and more than one vacuum tube amplifier are often used in radio circuits. (Stations that broadcast from greater distances can be heard when more amplifiers are used. Each vacuum tube added in the circuit increases the amplification.)

How Do Vacuum Tubes Transmit Oscillating Electromagnetic Waves? See Fig. 38.14(a). The primary coil in the plate (anode) circuit *induces* a current in the grid circuit. Because the electrons in the grid circuit are *induced to flow away from the grid,* the grid loses electrons. Loss of electrons or a deficiency of electrons causes the grid to become *positively charged.* The *combined attraction* of the positively charged grid and the positive plate causes a larger number of electrons to flow from the cathode to the plate. Again and again the primary coil induces the grid to become more positively charged *until* the plate circuit has attained its maximum capacity for attracting electrons. At this point, the plate circuit is said to be saturated. When this occurs, the flow of electrons in the plate circuit *decreases.*

When the current in the plate circuit decreases, the induced current in the grid circuit also decreases. When this happens, the electrons (negative charge stored on the movable plate of the condenser) on the movable plate are discharged, and they flow through the secondary coil to the stationary plate where their flow is *reversed.* The electrons now flow from the stationary plate through the coil to the grid. This causes the grid to become *negatively charged.* The increase and decrease in the plate circuit induces the grid to become first positively charged and then negatively charged. As the grid changes its charge from positive to negative, the current in the grid circuit flows *back and forth* (oscillates). As a result, the triode vacuum tube oscillates and transmits oscillating electromagnetic waves.

The same components that produced an oscillating current in the transistor oscillator are also present in a vacuum tube oscillator circuit. What are the names of these components? (A variable condenser and an induction coil.) Compare the diagram in Fig. 38.14(a) with the diagrams of the transistor oscillator circuit in Figs. 38.10 and 38.11. Why is the circuit in Fig. 38.14(a) incomplete? (Some of the components for its operation are missing.) Ask the pupils to look at the transistor oscillator circuit and name the components missing from the vacuum tube oscillator circuit. (Fixed condensers and resistors are missing.)

Compare the size and weight of a transistor with the size and weight of a vacuum tube. Ask the class to list some of the advantages and disadvantages of transistor and vacuum tube amplifiers (see Table 38.4). Also see Fig. 38.15.

7. How can a radio transmitter that will emit voice waves be made?

If a few changes are made in the oscillator circuit that the pupils wired in Inquiry 5, it can be converted into a radio transmitter that will send out both a carrier wave and a voice wave.

Table 38.4

A COMPARISON OF THE ADVANTAGES AND DISADVANTAGES OF TRANSISTORS AND VACUUM TUBES

Transistors		Vacuum Tubes	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Small size. Less weight. Less energy is wasted in heat. Less energy is required to operate them. Low voltage requirements make it possible to operate with solar batteries, fuel cells, and chemical cells. Amplify a larger range of wave frequencies. Can operate on direct or alternating current.	More expensive. Easily damaged by heat and by radiation.	Almost unlimited amplification is possible.	At present, amplification is limited by the noise factor, or static. Large size and weight eliminate their use in miniaturized electronic circuits. Require high voltages on which to operate. Cannot be used in miniaturized electronic circuits that operate on low voltages.

Open the knife switch shown in Fig. 38.10. From this transistor oscillator circuit, remove from contact screws No. 1 and 2, *the 1 K resistor*. In its place, connect the two wire conductors of a telephone transmitter. Check each connection very carefully to make sure that each device and each conductor is making a good contact.

Place a portable radio about 12 inches from the variable condenser and turn the radio on. Test the circuit, by opening and closing the knife switch, to find out whether it is complete. A sharp click should be heard in the telephone transmitter when the switch is closed. Adjust the movable plate on the variable condenser to a position in which the radio signal (a shrill whistle) can be heard. Pivot the movable plate *slightly* until the whistling stops. Ask one pupil to move close to the mouthpiece of the transmitter and say, "Hello." This "hello" will be heard coming from the radio speaker (see Fig. 38.16).

How far from the radio speaker can the pupil's voice be heard? Experiment to find out. (The distance will depend upon the sensitivity of the speaker in the portable radio.)

Pivot the movable plate back to the position from which the shrill whistling is produced. Have the same pupil talk into the mouthpiece of the telephone transmitter. Observe the results. (The whistling will stop and the muffled sound of the voice will be heard.) Why can the radio signal not be heard? (The vibrations made by the voice in the transmitter change or *modify* the radio signal or carrier waves.) How far from the radio

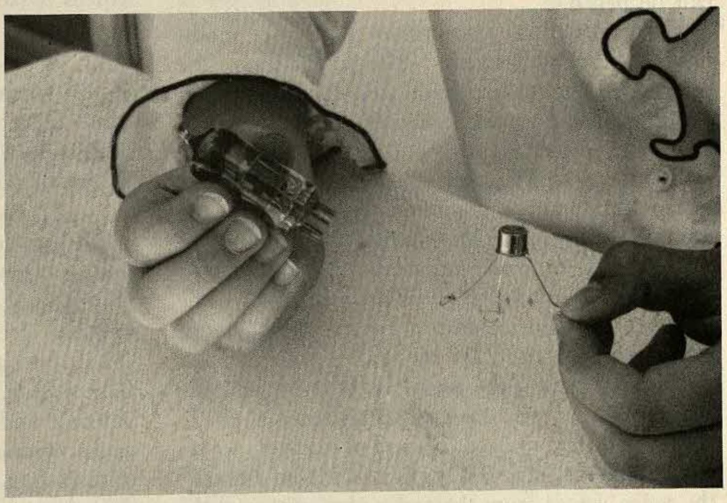


Fig. 38.15 The child compares the size of two amplifiers: the vacuum tube and the transistor.

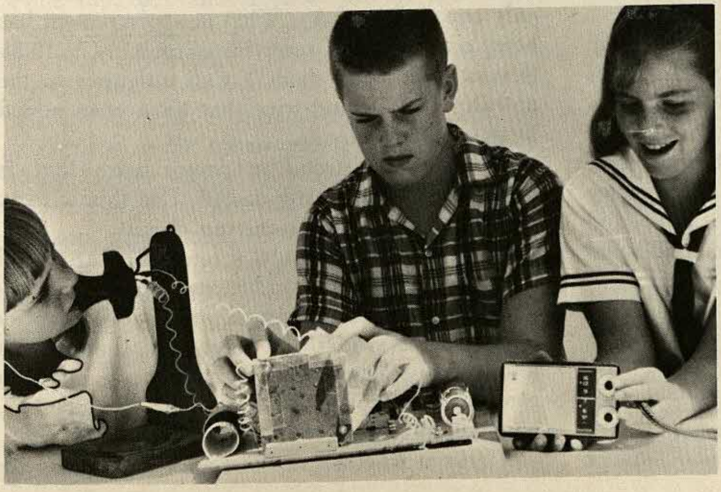


Fig. 38.16 The boy's homemade transmitter is broadcasting the girls voice to the transistor radio—concentration and success!

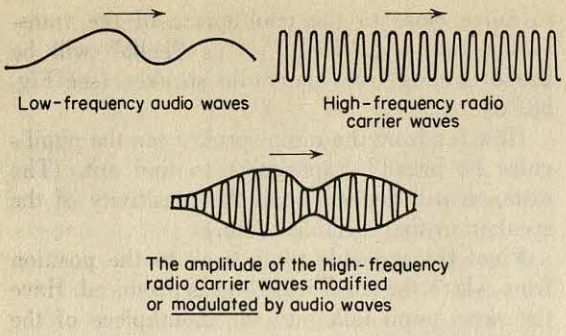

Low-frequency audio waves
High-frequency radio carrier waves
The amplitude of the high-frequency radio carrier waves modified or modulated by audio waves

Fig. 38.17 Amplitude modulation.

can the carrier waves (shrill whistle) be heard? How far can the voice be heard? (The distance from which the voice can be heard will be less than half the distance from which the whistle can be heard.)

What part of the transmitter changes or modifies the carrier waves? (The experiences the pupils had in working with the telephone circuit in Chap. 19, Inquiry 4 should enable them to answer this question.)

Open the knife switch. Remove the telephone transmitter from the circuit. Next remove the mouthpiece from the transmitter. Hold the transmitter close to one ear. Shake the transmitter gently and a soft swishing of the granules will be heard. If possible, obtain a transmitter that can be taken apart and let the pupils examine the two major parts—the metal diaphragm and the button that contains the carbon granules.

Develop the concept that the carrier waves provide the electrical energy needed to "carry" the voice waves from the radio transmitter to the radio receiver.

Ask one of the pupils to draw Fig. 38.17 on a large piece of paper. Use these wave diagrams to develop an understanding of amplitude modulation (AM). Amplitude modulation is used to transmit programs from radio stations that operate on the standard broadcasting frequency band. (Radio stations operating on this band are assigned a radio frequency between 550 and 1600 kilocycles.) Questions similar to the following will guide the class in their study of these wave patterns:

1. Which waves are longer—audio or radio carrier waves? (The audio waves are longer.)
2. Why are radio waves called carrier waves? (They are called carrier waves because they provide the energy (voltage) that makes it possible for the audio waves to travel from the broadcasting station to receiving sets.)
3. Study the wave patterns carefully and see why this method of transmitting voice waves is called amplitude modulation. (The amplitude of the carrier waves is modified or modulated by the audio waves.)
4. If necessary, use a ruler to answer the following question. Is the amplitude of the carrier waves increased or decreased by the audio wave? (The audio wave *may sometimes decrease*, but it *never increases* the amplitude of the carrier waves.)

If an oscilloscope is available in the physics laboratory of your school system, arrange for the pupils to go there to see the wave patterns their voices make on the oscilloscope screen.

8. How can a simple one-transistor radio receiving set be made or assembled? What is the function of the transistor junction diode in the receiving circuit?

If the school is located within a *10 to 15 mile radius* from a radio transmitting tower, the pupils may want to convert the pegboard transmitting circuit described in Inquiry 7 and Fig. 38.10 into a receiving circuit. (See Fig. 38.18.) The pupils should notice that both the transmitting and receiving circuits use many of the same components. Observe that the transmitting circuit has two coils of wire (coil A and coil B). Also, observe that the receiving circuit has only one coil (coil A). What new component has been added in the receiving circuit? (A 1N34 transistor junction diode.) Call attention to the antenna and ground wire that have been added in the *receiver circuit.*

Use No. 18 *strand* connector wire that is either rubber or plastic coated. Use this wire in *all parts* of the radio receiving circuit.

Observe that the only screws that are used to connect the wire conductors and the components in the receiver circuit are the two screws on the knife switch, the screws on the positive and negative terminals of the battery, the two screws on the plates of the variable condenser, and the antenna.

Find out whether any of the pupils know why

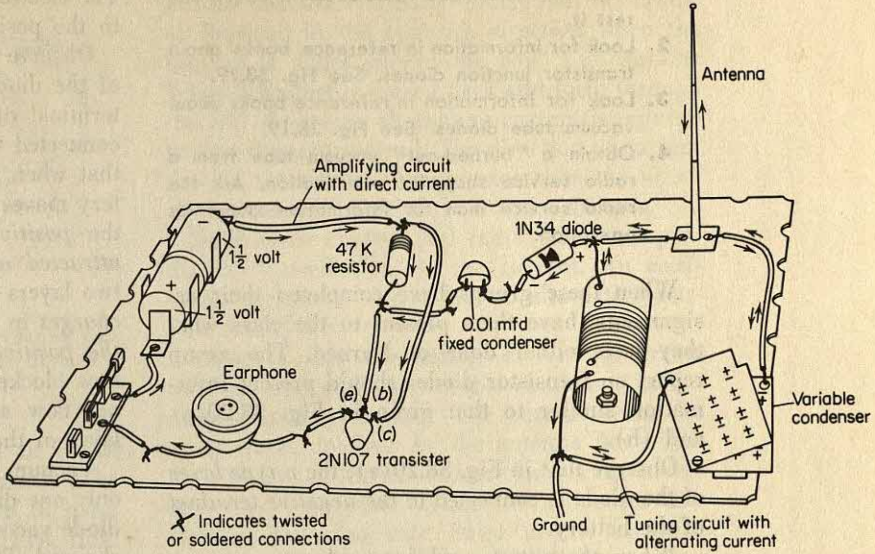


Fig. 38.18 Wiring for a one-transistor radio receiving circuit. Note: hold circuit to pegboard with gummed tape where needed; use wires as short as possible between each circuit component.

all of the other connector wires in this circuit are *joined directly together* rather than by means of machine screws for the connectors. (The wires are joined together to reduce the resistance.)

These wires may be joined by either twisting them tightly together or by soldering them with *cold, liquid solder*. This liquid solder can be purchased at hardware stores. Because transistors and diodes are easily damaged by the heat of an improperly used soldering iron, pupils can use liquid solder that is applied at room temperature.

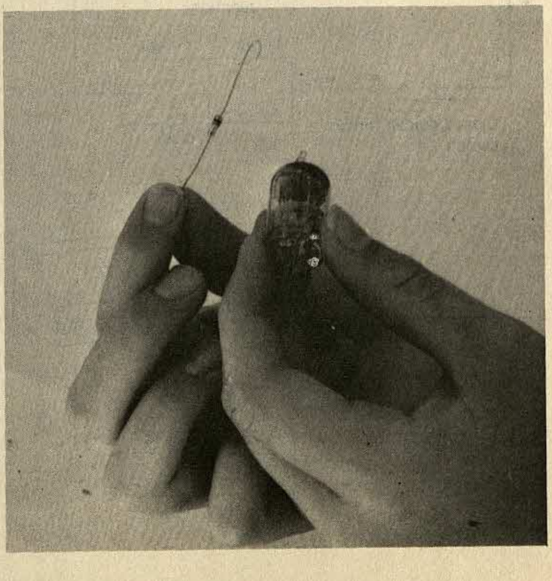
Discuss why the joined wires in the circuit also should be wrapped with electricians' tape. (The tape prevents a short circuit that would occur if a bare wire carrying electricity from the negative terminal of the battery touched a second bare wire that conducts electricity to the positive terminal of the battery.)

Emphasize the importance of the antenna. No radio carrier waves will enter the receiving set unless there is an antenna to intercept them. The antenna wire should be at least 50 feet long and attached to an insulator which will not absorb moisture. The antenna must not touch any metallic object other than the connector where it joins the radio circuit.

A good ground wire is also important. The contact with the metallic object (water faucet, water pipe, or radiator) should be clean. Remove any paint or corrosion before connecting the wire to the grounding object. The bare wire should be wrapped tightly around the pipe or grounding object.

Have one of the pupils make a large copy of Fig. 38.18 to use as a working plan. Divide the class into several groups and assign the following responsibilities:

Fig. 38.19 A child compares the sizes of a transistor diode and a vacuum tube diode.



1. **Wire the homemade radio receiver circuit and test it.**
2. **Look for information in reference books about transistor junction diodes. See Fig. 38.19.**
3. **Look for information in reference books about vacuum tube diodes. See Fig. 38.19.**
4. **Obtain a "burned-out" vacuum tube from a radio service shop for examination. Ask the radio service man for information about its operation.**

When these groups have completed their assignments, have them present to the class what they have either done or learned. The group report on transistor diodes should present information similar to that given in Fig. 38.20(a) and (b).

Observe that in Fig. 38.20(a), the *n type layer* of the diode is connected to the *negative terminal* of the battery.

When the n type and p type layers are connected as shown in this diagram, *electricity will be conducted* through the diode. The *electromotive force* of the battery *repels the electrons* through the n type layer into the p type layer. The electrons that enter the player are attracted to the positive electrode of the battery.

Observe in Fig. 38.20(b) that the n type layer of the diode *has been connected* to the positive terminal of the battery and that the p type is connected to the negative terminal. Also observe that when the electromotive force from the battery moves toward the p type layer of the diode, the *positive charges* in the p type layer are *attracted away from the junction* between the two layers of the crystal. Note that the *negative charges* in the n type layer are *attracted toward the positive electrode*. The flow of electrons is now blocked by the diode crystal. Electrons will not flow across the junction from the p type layer of the crystal to the n type layer.

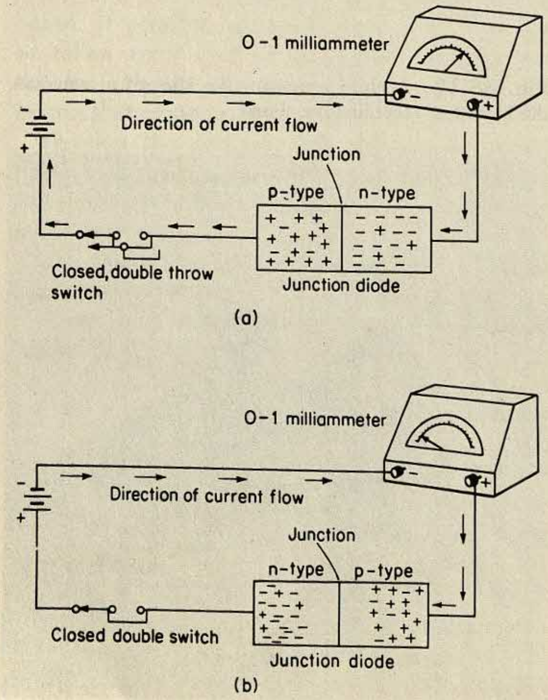
Vacuum tube diodes also conduct electricity in only one direction. Electrons will flow through a diode vacuum tube when the anode is positively charged. They will not flow through the vacuum tube diode when the anode is negatively charged. *Diodes are often called rectifiers because they change (rectify) alternating current into direct current.*

Help the class summarize the reports that have been given on diodes.

Because a battery supplies a direct current (a current that flows in only one direction), it may puzzle pupils why a battery operated radio receiving set needs a diode. In Inquiry 7 in this chapter the class worked with tuned radio transmitters. Both of these circuits contained oscillators. Find out whether the pupils remember and understand what they learned about these oscillators. (The oscillator produced an *oscillating current*. An oscillating current is also an *alternating current*. In the oscillator circuit, the electrical energy from the power supply forced the electrons to move in one direction. When this electromotive force *changed* (i.e. decreased), the electrons stored on one of the plates of the variable condenser discharged into the oscillator circuit and caused a *reverse flow* of current. A current that flows first in one direction and then in the other is said to oscillate.)

Further check the students' understanding of oscillation by asking them this question: Why are the symbols ± and ∓ used to designate an alternating current? (These symbols indicate that the location of the excess electrons stored in the variable condenser changes.) Draw the symbols on the chalkboard and ask a pupil to

Fig. 38.20 The transistor junction diode conducts electricity in only one direction.



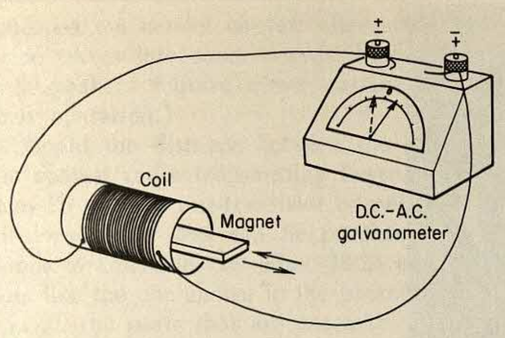


Fig. 38.21 Set-up for showing that alternating current reverses the direction in which it flows through a circuit.

use arrows to indicate the direction in which the electrons will move through the circuit. (The heads of the arrows should be drawn to point from the negative to the positive like this:

$$+ \longleftarrow - \quad \text{or} \quad - \longrightarrow +$$

Recall at least one experiment in this chapter in which direct current was changed into alternating current. (In each of the circuits that contained a coil and a variable condenser, direct current was changed into alternating current.) The simple generator in Fig. 38.21 also produces alternating current. Observe in Fig. 38.21 how the coil of wire used in the transmitter circuit is connected to a DC-AC galvanometer. Observe that the needle on the dial of the meter is deflected in *one direction when the magnet is pushed into the coil.* Also observe that the needle is deflected in the *opposite direction* when the magnet is pulled out of the coil. *Explanation:* When a magnet is moved back and forth through the coil of wire an alternating current is *induced* to flow through the coil. The direction of current flow in the circuit changes each time the *direction of the movement* of the magnet changes.

Both house current and radio waves are produced by oscillations in the current. An *oscillating current* is also called an alternating current (A.C.).

Compare this alternating current generator with the coil and the variable condenser in the radio receiving circuit. (The current from the radio waves received by the antenna flows into the coil and at the same time charges the moveable condenser plate. When the condenser discharges, the electricity flows in the opposite direction. See Figs. 38.18 and 38.21.)

The following experiments will provide further evidence that a transistor junction diode does change alternating current into direct current. Reverse the terminal connections of the 1N34 diode in the homemade receiving set. See Fig. 38.18. Close the knife switch and listen for the audible voice waves in the earphone. (The voice waves will not be heard. Only the click caused by the opening and closing of the switch and the buzz produced by the earphones will be audible.) Also, try this experiment. Wire a circuit as shown in Fig. 38.22.

Fig. 38.22 Determining the direction in which electricity flows through a transistor diode.

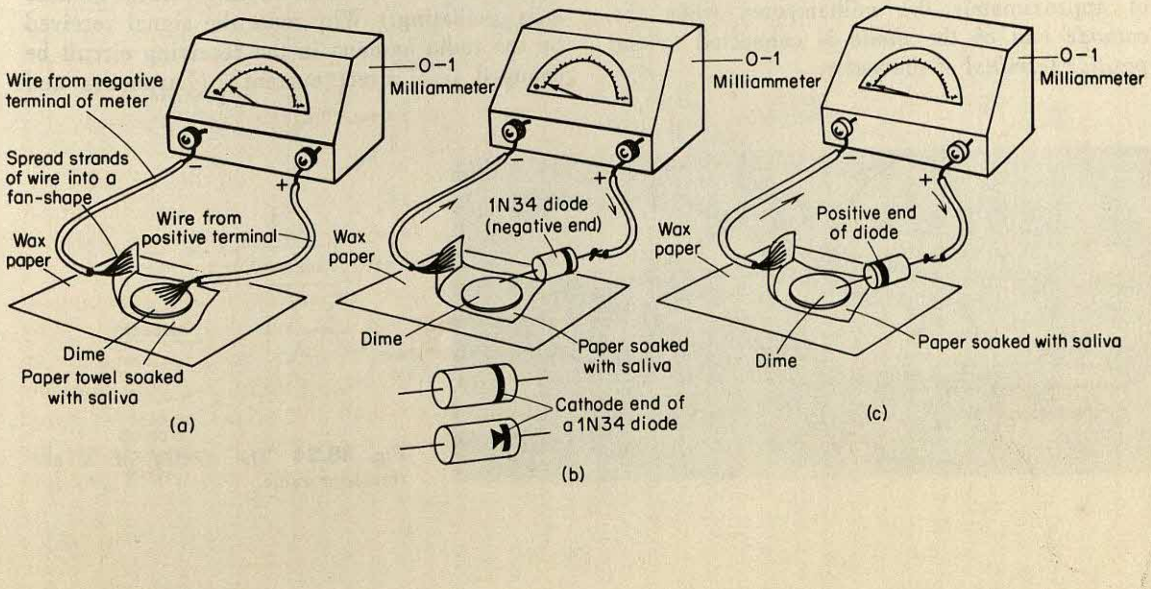


Fig. 38.23 Children using a one-transistor radio which they have assembled.

In Fig. 38.22(a) a chemical cell made from a shiny dime (10¢ piece) and a piece of a paper towel that is *soaked* in *saliva* will produce a current of electricity. This milliammeter registers the current at 0.2 milliamperes. Why is it possible for readings from different types of meters to vary? (Their resistance to the flow of electricity may vary.)

Find out whether an *acid* or a *base* is dissolved in the saliva that reacts with the metal strands of wire and releases electrons. What kinds of chemically treated paper would you use for this test? (Blue litmus paper and red litmus paper.) Try it. Results? If saliva turns *blue* litmus to *red*, an acid is present. If it turns *red* litmus to *blue*, a base is present. (*Saliva* will turn *blue litmus* to *red*. An *acid* is present.)

In Fig. 38.22(b) the meter registers a current of approximately 0.1 milliamperes when the *cathode* end of the *diode* is connected to the *positive terminal* of the meter.

The cathode end or *terminal* of the diode will be marked with either a *black band* or the *head* of an *arrow pointed toward part of* a *spiral* band.

In Fig. 38.22(c) the meter will register very little, *if any*, current when the anode is connected to the positive terminal of the meter. What does this part of the experiment show? (The diode *blocks most* of the electricity when the *anode* is connected to the *positive terminal* of the *meter*.) What did the (b) part of the experiment show? (The diode *conducts* electricity when the *cathode* is connected to the *positive terminal* of the *meter*.)

Where is the alternating current in the radio receiving circuit? (The radio signal received by the antenna is composed of oscillating electromagnetic waves.) Is this current direct or alternating current? (It is alternating current because it is oscillating.) Why must the signal received by the radio antenna in the receiving circuit be changed into direct current? (Earphones and

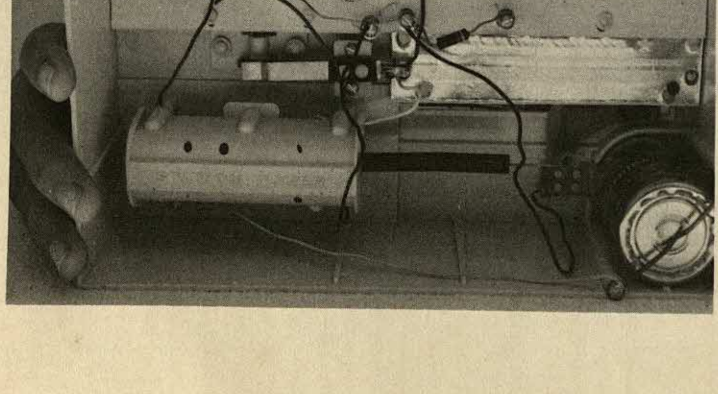


Fig. 38.24 The circuit of a one-transistor radio.

loudspeakers cannot convert alternating current voice waves into sound waves. Both earphones and speakers require direct current waves for their operation.)

Should the distance between the school and the nearest radio transmitting tower be greater than 15 miles, a one-transistor educational radio kit for $10 or less can be purchased for the pupils to assemble (see Figs. 38.23 and 38.24). Kits like the one shown in the photographs contain all the parts that are necessary for wiring the circuit with the exception of the dry cells and the ground and antenna wire.

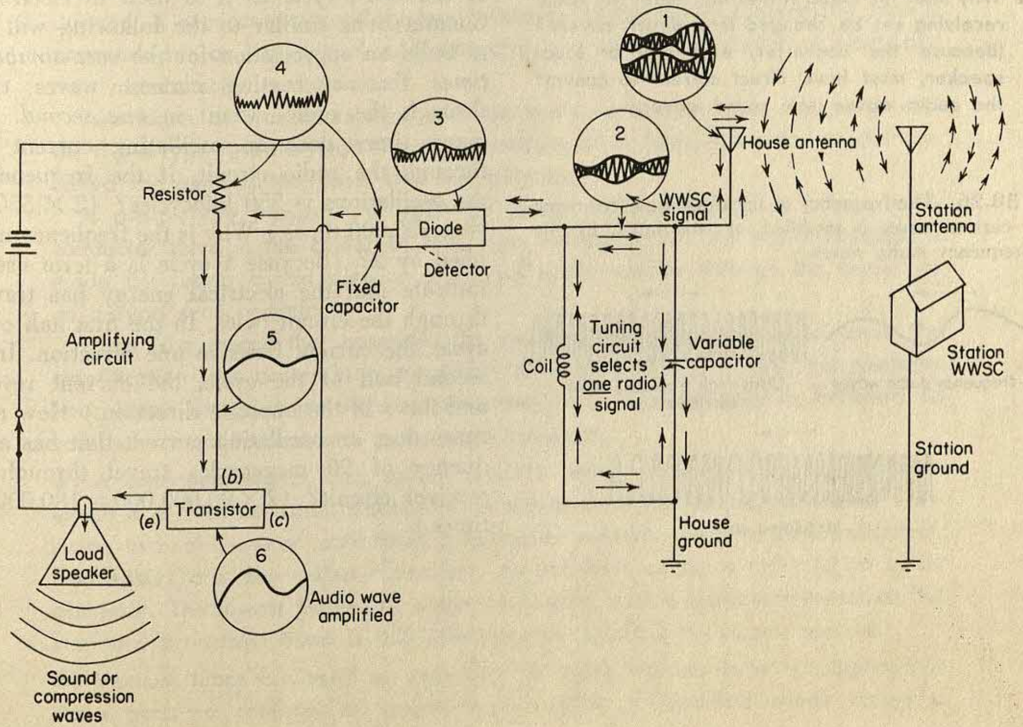
9. What are the essential parts in radio receiving sets? What is the function of each? What is meant by AM and FM radio? What is a cycle?

List the esssential parts in a radio receiving circuit. Also, explain the function of each of these parts. The list and explanations should be similar to the following:

1. *Antenna.* The antenna intercepts radio carrier waves. The electromagnetic field surrounding the waves induces weak alternating currents in the antenna.
2. *Oscillator or tuning circuit.* The oscillator, a tuning circuit containing a coil and a variable condenser, conducts only one carrier wave frequency into the receiving set.
3. *Detector or diode.* The detector changes the alternating current waves into direct current waves.
4. *Fixed capacitor and resistor.* They separate the audio waves from the carrier waves.
5. *Amplifier, transistor or modified triode tube.* It amplifies weak signals.
6. *Reproducer or converter, earphones or loudspeakers.* They receive audio waves and convert them into sound waves (compression waves).

Ask a pupil to reproduce Fig. 38.25. Use this large schematic of the homemade one-transistor radio receiver to discuss *what happened to the modified carrier waves as they traveled through the circuit.* In the circles numbered 1 through 6 in Fig. 38.25, notice how the radio carrier wave

Fig. 38.25 The changes that occur to weak radio waves in the homemade one-transistor radio.

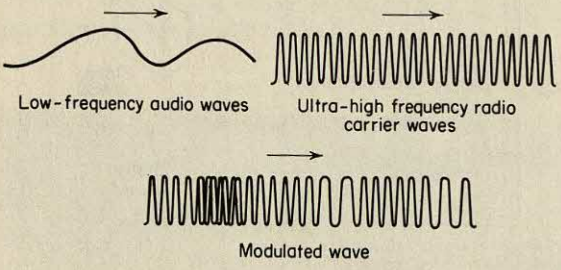


is changed by the different parts of the radio. Circle No. 1 shows two modified carrier waves being intercepted by the house antenna. In circle No. 2 the carrier wave from radio station WWSC has been selected by the tuning circuit. In circle No. 3 one-half of the WWSC carrier wave signal has been removed by the diode dectector. The complete signal was an alternating current signal. The half that is conducted *by the diode* is a direct current signal. In circle No. 4 the audio wave has been separated from the carrier wave by the fixed capacitor and resistor. In circle No. 5 the audio part of the radio wave is received by the *base* of the transistor. In circle No. 6 the audio wave is amplified by the transistor.

Questions similar to these will help to clarify the concepts of the changes that occur as the radio waves travel from one component in the circuit to another:

1. Why do radio receiving sets usually have more than one amplifier? (The radio signals are weak. Each amplifier in the circuit increases the amplitude (intensity) of the signal.)
2. Which components in the receiving circuit separate the audio waves from the carrier waves? (The fixed condenser and the resistor)
3. Why must the audio waves that enter the radio receiving set be changed into *direct current*? (Because the converter, earphone or loudspeaker, must have direct current to convert the audio waves into sound waves.)

Fig. 38.26 The frequency of the ultra high frequency radio carrier waves is modified, or *modulated*, by the low frequency audio waves.


Low-frequency audio waves
Ultra-high frequency radio carrier waves
Modulated wave

Amplitude modulation and frequency modulation are two of the most commonly used methods for the transmission of audio waves. See Inquiry 7 and Figs. 38.17 and 38.26 for diagrams of these two methods. The following questions can be answered by carefully studying the diagrams in these figures.

1. What happens to the carrier waves if the transmtting station uses amplitude modulation? (The amplitude, the height or intensity, of the carrier waves is varied by the signal strength of the audio waves they carry.)
2. What happens to the carrier waves if frequency modulation is used? (The carrier waves' frequency, number of oscillations per second, is varied by the signal strength of the audio waves they carry.)
3. Which method of modulation can carry audio waves? (Both methods can be used. *High* frequency carrier waves (550 to 1600 kilocycles) carry an audio wave signal by amplitude modulation, AM. *Ultra high* frequency carrier waves (88 to 108 megacycles) carry an audio wave signal by frequency modulation, FM.)

Find out whether the pupils know the meaning of the word *cycle* as it is used in electronics. Computations similar to the following will help to build an appreciation for the *vast number of times* that alternating current waves travel through the radio circuit in *one second.* How many times does an oscillating current flow through the radio circuit, if the frequency of the oscillations is 550 kilocycles? (2 × 550,000 = 1,100,000 times.) Why is the frequency multiplied by 2? (Because a cycle is a term used to indicate that the electrical energy has traveled through the circuit twice. In the first half of the cycle, the current flows in one direction. In the second half of the cycle, the current reverses and flows in the opposite direction.) How many times does an oscillating current that has a frequency of 90 megacycles travel through the receiver circuit? (2 × 90,000,000 = 180,000,000 times.)

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. A resistor is an essential part of an electrical circuit. A resistor decreases (holds back) both the voltage and amperage in an electrical circuit. As a resistor's length increases, its resistance increases and reduces the intensity of the current in the circuit. As a resistor's width increases, its resistance decreases and more current flows in the circuit. Resistance is measured in ohms and kilohms. One kilohm is equal to 1000 ohms.

A rheostat is an adjustable or variable resistor, which can be used either to increase or decrease the current in a circuit. Rheostats are used for many purposes, such as controlling the brightness of lights and the speed of electric motors. The volume control on both radio and television sets is a special type of rheostat called a potentiometer. Resistors that have high resistance decrease the current more than resistors that have lower resistance.

2. Almost all electronic devices contain amplifiers. Both transistors and vacuum tubes are used to amplify radio and television waves. Transistors operate on lower voltages and amperages than vacuum tube amplifiers. Resistors are used to regulate the current or amperage. The amount of current flowing in the base circuit of a transistor determines the amount of current flowing in the collector circuit. Variations in the base current cause *the same variation* in the amplified current. Transistors are used to control and to amplify the current in radio and television circuits.

3. The symbols used in electrical circuits are shortcuts for words and for pictures of objects. Symbols are important in all forms of communication.

4. The crystal in a transistor is composed of two different kinds of semiconductors. A semiconductor offers less resistance to the flow of electricity than a nonconductor or insulator. A semiconductor is a poorer conductor of electricity than metals, salts, and acids.

Two kinds of transistors that are commonly used are called the p-n-p and the n-p-n type fused crystal. The three sections of a fused transistor crystal are called the emitter, the base, and the collector.

A p-n-p type transistor is made by fusing a thin piece of an n type semiconductor through the center of a p type semiconductor. An n-p-n transistor is made by fusing a thin slice of a p type semiconductor through the center of an n type semiconductor.

There is a theory that describes the changes that are believed to cause the amplification that occurs in a transistor. According to this theory, *the electron-poor layers attract more electrons than they lack.* This attraction is believed to cause the amplification in a p-n-p type transistor.

5. A continuous signal, also called a *carrier wave,* is emitted by the oscillator circuit in a transistor radio transmitter. A simple oscillator circuit contains a transistor, two coils, one or more fixed condensers, resistors, and a variable condenser. Condensers are also called capacitors. An oscillator circuit is referred to as an oscillator. The lowest frequency wave (oscillation) that a radio can detect on the standard broadcast band is 550 kilocycles or 550,000 cycles per second.

6. Vacuum tubes are used as *amplifiers.* A triode vacuum tube is composed of three parts—a cathode, an anode, and a grid. A modified triode called a pentode is commonly used for amplifying radio waves. A pentode is composed of a cathode, an anode, and *three* grids. The three different parts of a vacuum tube can be compared to the three parts of a transistor. The cathode emits millions of electrons when it is heated. The anode (the plate) collects the electrons that are emitted by the cathode. The grid controls and regulates the flow of electrons that move from the cathode to the plate.

Vacuum tubes are also used as *oscillators* to produce the electromagnetic waves on which radio and television programs are transmitted.

Vacuum tubes are fragile and easily broken. Transistors are easily damaged by heat, moisture, and radiation. A transistor's miniature size and its low voltage requirements make it a valuable device to use for amplifying current in electronic circuits in which both size and weight are important factors.

7. The radio signal or carrier wave provides the energy needed to "carry" audio waves from the broadcasting station to radio receiving sets. Radio waves have a shorter wave length and a higher frequency than sound waves. The transmitter in the broadcasting station changes sound waves into electrical waves that are called audio waves. Audio waves modulate the amplitude of the carrier waves. This is called amplitude modulation. Radio stations that operate on frequencies between 550 and 1600 kilocycles use amplitude modulation to broadcast programs.

8. The antenna intercepts and conducts a transmitted radio wave into the radio receiving set. Radio waves are modulated, oscillating, high frequency waves, called carrier waves. The carrier waves are modulated by the audio (voice) waves that they transmit. The variable condenser in the tuning circuit selects the broadcast frequency that is amplified. The diode in the receiving circuit changes the oscillating radio waves into direct waves. The transistor amplifies the direct current waves. The earphone, or speaker, converts the audio waves into compression sound waves, or compression waves.

9. There are a number of essential parts in radio receiving circuits. They are the antenna, the oscillator, the detector, the fixed condenser and resistor, the amplifier, and the sound reproducer. Two different methods are commonly used to transmit audio waves. Audio waves can be carried by either high frequency or ultra high frequency radio carrier waves. The *amplitude* of *high frequency* radio carrier waves is modulated by the audio waves they carry. Amplitude modulation is used by carrier waves that have frequencies between 550 and 1600 kilocycles. The *frequency* of *ultra high* frequency radio carrier waves is modulated by the audio waves they carry. Frequency modulation is used for carrier waves that have frequencies between 88 and 108 megacycles. During one cycle oscillating waves travel through the circuit in two directions.

Chapter Thirty-Nine

Television Receivers and Transmitters

INQUIRIES

1. What are some of the important parts of a black and white television picture tube? What is the function of each part? What causes the image to form on the screen? Why is a complete image seen on the screen?
2. What are some of the ways in which a color television tube differs from a black and white picture tube? What causes the colored image to appear on the viewing screen?
3. How does a television camera tube work? How does it differ from a television picture tube? How are television programs transmitted and received?

1. What are some of the important parts of a black and white television picture tube? What is the function of each part? What causes the image to form on the screen? Why is a complete image seen on the screen?

The following learnings are basic for developing this inquiry. If the pupils are not already familiar with these facts, use the experiences in Chap. 18 to develop this background information.

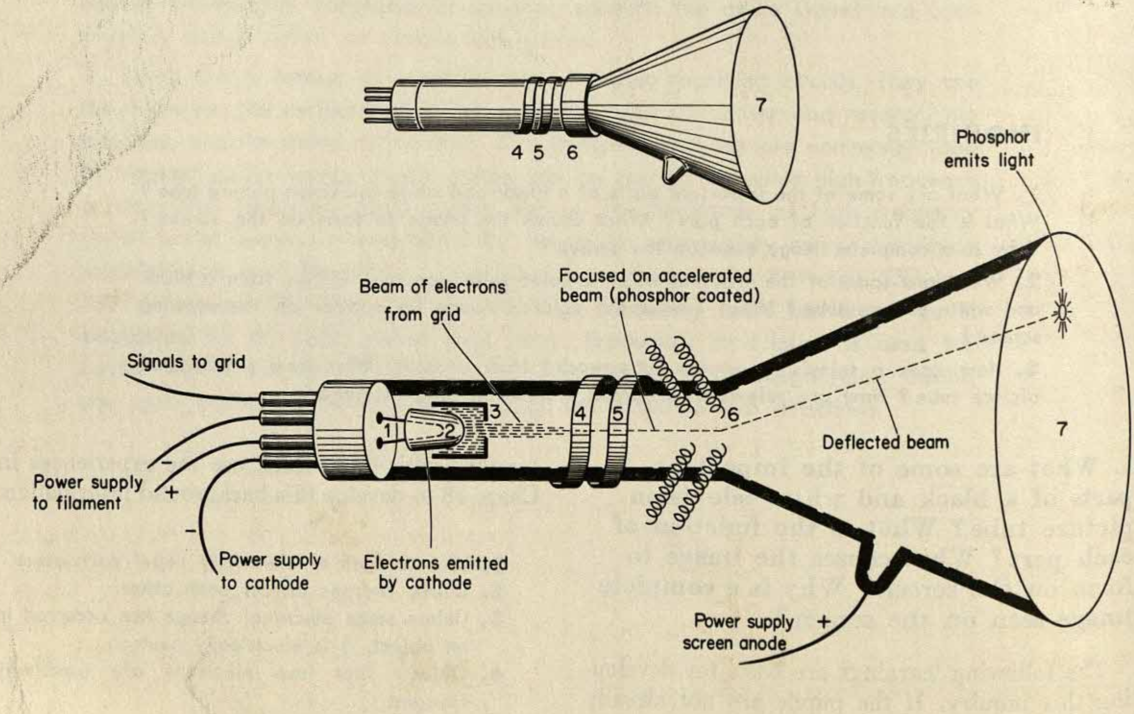
1. Like charges of electricity repel each other.
2. Unlike charges attract each other.
3. Unless some electrical change has occurred in an object, it is electrically neutral.
4. Objects that lose electrons are positively charged.

Table 39.1

LIKENESSES AND DIFFERENCES BETWEEN AN ELECTROSTATIC GENERATOR AND A TELEVISION PICTURE TUBE

Likenesses		Differences	
Electrostatic Generator	Television Picture Tube	Electrostatic Generator	Television Picture Tube
1. *Heat energy* from the friction between the soft metallic brushes and the generator plates *releases electrons* from the plates.	1. *Heat energy releases electrons* from the cathode.	1. *Electron movement not well controlled.*	1. *Electron movement well controlled.*
2. Sparks which give off *light energy* occur *when the electrons jump* from the negatively charged sphere to the oppositely charged positive sphere.	2. *Light energy* is emitted by the phosphors coated on the screen end of the tube *when electrons strike them.*	2. *More voltage needed* to move electrons across spark gap.	2. *Less voltage needed* to move electrons from cathode to screen.
		3. Electrons move *through air.*	3. Electrons move *through vacuum.*
		4. Electrons *do not travel well through air.*	4. Electrons *travel well through a vacuum.*

Fig. 39.1 The television tube changes the video signal received into an electron picture. Key: (1) filament or heater; (2) cathode; (3) grid; (4) focusing anodes; (5) accelerating anodes; (6) deflection coils; (7) screen anode.



5. **Objects that gain electrons are negatively charged.**
6. **An object that is neutral has neither gained nor lost electrons.**
7. **Objects that have gained or lost many electrons are more strongly charged than objects that have gained or lost only a few electrons.**

Chapter 36 also has suggested experiences that are important to the understanding of this investigation. In Inquiry 3 of that chapter the pupils learned that when light shines on the chemical in a photoelectric cell, electrons will be emitted and an electric current will flow. In Inquiry 4, electrostatic generators were used to charge homemade condensers. A television picture tube is similar in some ways *to an electrostatic generator* (see Table 39.1).

The television tube has devices that control both the direction and the number of electrons that move through it (see Fig. 39.1). Have one of the pupils draw a large diagram of the picture tube shown in Fig. 39.1. Also help them locate information that will be useful in the solution of this problem. After the reference reading has been completed, provide experiences similar to the following ones. Use the diagram of Fig. 39.1 as a basis for a discussion of the parts of the picture tube and their functions.

A television picture tube is similar in a number of ways to a triode tube. Both have a cathode, a control grid, and at least one anode. (See Chap. 38, Inquiry 6.) The following numbers preceding the parts of a television picture tube correspond with the numbers in Fig. 39.1.

1. **Filament.** An electromotive force of several thousand volts heats the metal filament in the picture tube.

2. **Cathode.** A metallic-cup-shaped cathode encloses the filament. When the cathode is heated by the filament, the cathode emits millions of electrons.

3. **Control Grid.** Surrounding the cathode is a control grid. The control grid directs the electrons, which pass through it, into a very narrow beam. The control grid is connected to the negative electrode of the power source and to the antenna circuit. The variations in the intensity of the picture signal (video wave energy) that enter the grid from the antenna cause the grid to become more or less negatively charged. When the control grid has a stronger negative voltage, it repels more of the electrons emitted from the cathode. (Like charges repel each other.) This causes a weaker beam of electrons to pass through the grid to the phosphor-coated screen. When the picture signal causes the grid to have a weaker negative voltage, more electrons stream through it to the screen. This causes a stronger beam of electrons to pass through the grid. *Variations in the intensity of the video signal* produce *the same variations in the electron beam* that passes through the grid.

4–5 **Anodes.** There are three anodes (positive electrodes) in a picture tube. Two anodes are located between the grid and the screen. The screen is the third anode. The very high positive voltage that is applied to the anode nearest the electron gun focuses the electron beam so that it will come to a sharp point on the screen. The very high positive voltage on the second anode pulls or accelerates the electrons in the beam.

6. **Deflecting Coils.** Because the accelerated electron beam is focused to strike a tiny spot of phosphor on the screen, it must sweep across the screen many times to form a complete picture. The electron beam sweeps across the screen from left to right until it has moved from the top to the bottom of the screen. This process of forming a picture on a screen is called *scanning.* Four magnetic deflection coils control the scanning of the electron beam. These deflection coils are located in a deflection yoke that is fitted around the neck of the picture tube. There is a magnetic field around the electron beam just as there is a magnetic field around a wire carrying a current of electricity. By controlling the strength of the magnetic fields of the coils, the coils can be made to push the beam from left to right, and from the top to the bottom of the screen and back again.

Two of the magnetic coils control the horizontal movement of the beam and two control the vertical movement. At the end of each scan, the beam must be shut off (blanked), while the deflection coils push the beam to the left hand side of the screen to start another scan. Each horizontal movement across the screen is called a scan line. As soon as the electron beam returns to the left hand side of the screen, the vertical deflection coils pull the beam slightly downward, so that the beam scans another line that is a little below the previous one. The point of the electron beam scans the screen 525 times in 1/30th of a second on screens that *are sold* in the United

States. European countries do not usually use 525 scan lines. Some countries use more lines and some use fewer.

When the electron beam reaches the bottom of the screen, the beam is blanked (shut off), while the vertical deflection coils return the beam to the top of the screen to start a new picture. Without such blanking of the electron beam on its return sweeps, the electron image being formed on the screen would be blurred.

The blanking of the electron beam *in the picture tube* is synchronized (timed) with the blanking of the electron beam *in the television camera tube.* The signal to shut off the electron beam in the picture tube and in the television camera tube is called the *blanking pulse.* This blanking pulse is a part of the picture signal that enters the control grid of the television picture tube.

7. **Screen.** The phosphor-coated screen is connected to the positive electrode of the power supply. As the electron beam sweeps across (scans) the screen, each speck of phosphor that the beam tip strikes emits light. The amount of light emitted is in direct proportion to the intensity of the electron beam. If no electrons strike the specks, no light is emitted. If a strong beam strikes the specks, much light is emitted. If a weaker beam strikes the screen, less light is given off.

Questions for Discussion. How many round trips does the electron beam make to produce one scene on the screen? (2 × 525 = 1050 trips.) How long does it take for these 1050 trips? (1/30th of a second.) Why is the scene formed on the screen called an electron image? (Because the electrons cause the phosphors to emit light.) Why is the image black and white? (If the pupils have had the experiences suggested in Chap. 29, they should be able to answer this question. Black is the absence of light. White is a mixture of the various colors of light.) What causes the different shades of gray in a television picture? (Different shades of gray are produced when the intensity of the electron beam is between its maximum and minimum intensity.)

Figure 39.2 shows how an image is formed on the phosphor coated picture tube. Have the children try to make a picture similar to the one of the oriental cold drink peddler. This picture was traced from an engraved plate by placing a piece of paper over the engraving and drawing horizontal lines across the paper. The tracing, or impression, looks like the black and white lines that can be seen by looking closely at the image on the television screen.

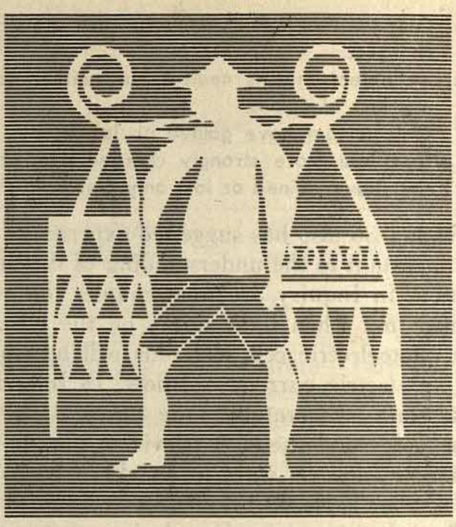


Fig. 39.2 How the image is formed on a television picture tube screen.

Complete and Discuss the Experiences That Follow. These experiences should help the class to state what they have learned about picture tubes and how the tubes form images.

The image of the televised scene begins to form in the upper left hand corner of the screen, where the electron beam starts the scanning process. Look closely at the image on a television screen. It will appear to be composed of numerous lines. These lines will also appear to vary in the amount of light that is being emitted. Some of the lines will seem to produce the visual sensation of black; others of gray; and still others of a combination of black, gray, and white. These visual sensations of black, gray, and white are not optical illusions, *but the lines are illusions.* Actually, the image is composed of many thousands of dots of phosphor that are emitting varying amounts of light. What will be the visual sensation if the spots are emitting no light? (Black.) Some light? (Gray.) Much light? (White.)

The lines on the screen are not the only illusions that make it possible for people to see television programs. The image appears on the screen in 525 lines. Why does the image seem to be *formed as a whole?* [There are two reasons: (1) the electron beam makes its 525 trips across the entire screen in 1/30th of a second; (2) our eyes continue to "see" the image of an object for a short period of time after the light from the image has disappeared.] If the pupils have had the experiences suggested in Chap. 34, they should know that this effect is called *the afterimage.* Repeat some of the experiments with afterimages that are suggested in Chap. 34.

Also try these experiments. Draw an apple or some other fruit on a 4-inch square of white cardboard. Draw either a fruit bowl or a basket on the back side of the same cardboard. Cut a slit in the top of a round pencil. (A wooden dowel of approximately the same diameter as a pencil may also be used.) Insert the cardboard in the slit and roll the tubular shaped object by rubbing the palms of the hands back and forth very rapidly. What appears to have happened to the apple? (The apple seems to be in the bowl or basket.) Use additional squares of cardboard and draw objects on both the front and back sides of each square. (Such objects as a bird and a cage, a flower and a vase, and a chair and a stick figure of a boy in a sitting position may be used.) One at a time, place a square of cardboard in the slit of the roller. Rotate the roller and observe each of the results. What happens? (Each time the object on one side of the cardboard square *appears to be in* the object on the back side of the square.) Why? (The afterimage of the object on the front of the square was being "seen," while the object on the back of the card was viewed.)

Obtain a pen-sized flashlight. Darken the room. Ask a pupil to turn on the flashlight switch and hold the flashlight in his right hand. Then, ask him to rotate his right arm very rapidly in a small circle. What shape does the light from the flashlight seem to have? (It seems to form a ring of light.) Move the flashlight in a larger circle. Results? (The ring appears to be larger.) When the circle is very large the ring will disappear. Rotate the flashlight in smaller and smaller circles. What shape does the light seem to have? (It will look like a lighted pinwheel.)

Summarize the results of these experiments with afterimages. What conditions are similar in each experiment to cause the optical illusion of the light from the object *being where it was not?* (The speed with which the objects were rotated.)

Why do the 525 lines in the image on the screen of a picture tube appear as a whole picture? (The afterimages persist *for a longer period of time* than it takes the beam to scan the 525 rows of phosphor dots. The afterimage persists for 1/16 of a second. The electron beam scans the screen in 1/30th of a second.)

Borrow a reel of movie film and examine some of the individual frames with a magnifying glass. Find out whether the pupils can *apply* their learnings about the formation of the electron image on the picture tube screen and their experiences with afterimages *to the illusion of motion* from the frames of movie film. Ask them questions similar to the following ones.

1. How rapidly must these frames (separate pictures) in the film be projected to produce the illusion of movement? (At least 16 frames each second. Many projectors project 20 frames per second.)
2. Why is 16 the minimum number of frames that must be projected in one second? (The afterimage persists for about 1/16th of a second.)
3. How many images (scenes) appear on the screen of a television tube each second? (30.)
4. How did you know that the number of images must be 30? (The screen is scanned in 1/30th of a second and the images appear consecutively.)
5. How many lines of televised scenes are transmitted to the television receiving set in each second? (525 × 30 = 15,750 lines.)

Some of the students who like to draw may enjoy making animated figures on sets of 25 to 30 filing cards (3 by 5 inches in size). When the cards are flipped very rapidly, they will produce the illusion of movement. Have these students practice flipping a set of blank cards before they draw on them. Hold the set in the left hand and flip the cards with the right thumb. Make certain that they observe that at least ½ inch of the left hand side of the cards cannot be seen. For this reason the animated objects should be drawn at least ½ inch away from the left side of the cards.

Ask the pupils who are making filing card movies to select some theme such as two children, one throwing a ball and the other catching it; a newsboy throwing a newspaper near a customer's door; a person skating, water skiing, or dancing; or the launching of a rocket. Discuss some of the things that must be considered when making animated pictures.

1. The animated object that is chosen should be easy to draw.
2. Unless the pupils are skilled in drawing, the details in the scene should be kept to a minimum.
3. The sequence of movements should be planned and drawn on paper before they are transferred to the cards.
4. Part, or all, of the object should be in a slightly different position on each card in the sequence. For example, if the newsboy theme is chosen, in the first picture he could be getting ready to throw the newspaper. On the next several cards his arm would be shown as having moved forward about one arm's width from the position it was in on the preceding card. Then a final series of pictures should show the release of the newspaper from the hand and the paper soaring through the air to drop near the door.
5. After drawing the sequence on paper, cut out and fasten each drawing on one card with paper clips. Flip the cards rapidly to find out whether the objects appear to move. Make any adjustments in the drawings that are necessary to get good movement.
6. Use carbon paper and trace each drawing in the sequence on a separate filing card.

2. What are some of the ways in which a color television tube differs from a black and white picture tube? What causes the colored image to appear on the viewing screen?

Locate information about the different kinds of color television picture tubes and how the colors of the image are reproduced on the viewing screen. Also ask a pupil to draw a large diagram like the one shown in Fig. 39.3. Use this large diagram when discussing color television tubes. Information similar to the following can be found in science encyclopedias, high school physical science books, elementary physics books, and books on electronics that are written for laymen.

There are different kinds of color television picture tubes. However, all color tubes are modified black and white picture tubes. A color television tube contains the important parts found in a black and white tube and a few additional parts as well.

The two most important differences between the various kinds of color tubes are: (1) the number of electron beams used; and (2) the patterns in which the phosphors are coated on the screen.

One kind of color picture tube has one electron gun with three control grids that separate the wave signals in the color picture signal received from the broadcasting station. Another kind uses additional deflection coils for this purpose. A third kind uses three electron guns and a shadow mask containing thousands of holes to direct the three electron beams to a particular phosphor dot on the viewing screen.

The viewing screens of each of these three kinds of color tubes are coated with *three phosphor compounds*. One of the phosphor compounds emits *blue* light when the electron beam strikes it. A second kind of phosphor emits *red* light when the beam strikes it, and the third kind emits a *green* light.

Two methods are commonly used to distribute the three phosphor compounds on the viewing screen. In some kinds of color tubes, the screen is coated in vertical stripes or lines. The phosphor emitting red light, the phosphor emitting blue light and the phosphor emitting green light are distributed in vertical lines repeated again and again to cover the screen. The second method of distributing the three phosphor compounds is called the checkerboard or group dot method. The phosphors are coated on the screen in groups, one dot of each kind of phosphor to a group (see Fig. 39.3).

Phosphors that are commonly used to coat television viewing screens are as follows:

1. Zinc sulfide combined with silver—commonly used for black and white picture tubes—will emit white light.
2. Zinc orthosilicate will emit green light.
3. Cadmium tungstate will emit blue light.
4. Cadmium borate will emit red light.

Obtain a collection of fluorescent and phosphorescent minerals and a mineral light (an ultraviolet light). In a very dark room, observe the colors emitted by the minerals in this collection. A windowless closet or a photographic darkroom would be ideal for this observation. It is possible to see each color in the rainbow emitted by a collection that contains a large variety of minerals. Some of the minerals may also emit white light. (See Chap. 6, Inquiry 6.)

After discussing the information on color tele-

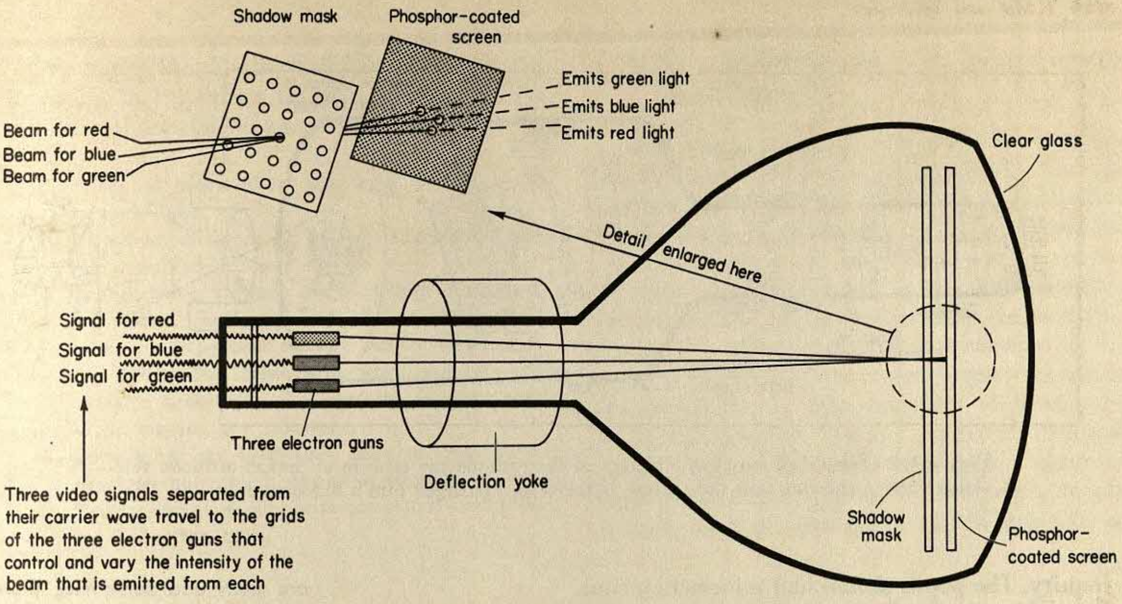


Fig. 39.3 Simplified diagram of one kind of cathode ray tube used for receiving color television pictures. This tube contains a mask that guides the beams from the three electron guns toward the phosphor-coated screen. The beam carrying the intensity of the red video signal, for example, must strike *only* the phosphor that emits red light if the color picture is to be accurately reproduced.

vision tubes, find out whether pupils can explain why only three colors of light (red, blue, and green) are needed to produce the different colors that appear on the viewing screen. If the children do not know the reasons, have them do some of the experiments suggested in Chap. 29, Inquiry 6. (By mixing the proper proportions of two of the three colors of light, a third color sensation is produced. For example, red and green light mix to produce the sensation of yellow light. From combinations of red, blue, and green light, a full color spectrum can be achieved.)

Also, find out whether the class can answer questions similar to the following ones.

1. What causes the visual sensations of different colors on a television screen? (The kinds of phosphors that are coated on the screen. Some phosphors emit red light; others blue light; and still others green light.)
2. How many different color-emitting phosphors are needed to produce the visual sensation of all the colors in the spectrum? (3.) Name these colors. (Red, blue, and green.)
3. Why is it not necessary to coat the kind of phosphor that emits white light on the screen in the color picture tube? (Because a combination of the three colors, red, green, and blue produces white light.)
4. If three color signals are transmitted sequentially in the picture signal, what electronic device do you think a broadcasting station probably has to make it possible for its color programs to be viewed on a black and white screen? (An electronic color mixer which forms *a brightness signal.* The carrier waves transmit not only the three color sequence signals but also the brightness signal. It is the brightness signal which black and white tubes use when they show a color broadcast in black and white.)

Use the diagrams of the black and white and the color television tubes to compare the likeness and differences between the tubes.

3. How does a television camera tube work? How does it differ from a television picture tube? How are television programs transmitted and received?

Make an enlarged diagram of Fig. 39.4. Assign to other pupils the responsibility for locating information that will be useful in this

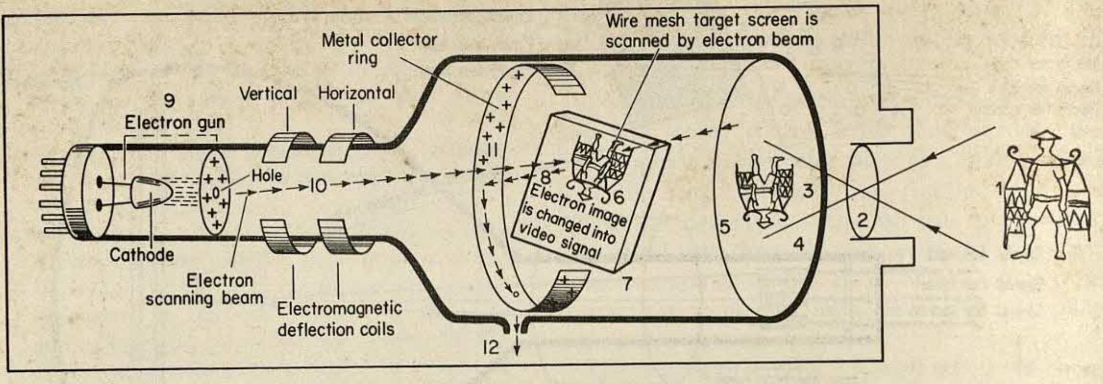

Wire mesh target screen is scanned by electron beam
Metal collector ring
9
Electron gun
Vertical
Horizontal
Hole
10
11
8
Electron image is changed into video signal
6
3
2
1
5
4
7
Cathode
Electron scanning beam
Electromagnetic deflection coils
12

Fig. 39.4 Simplified cut-away diagram of the cathode ray tube in an image orthicon television camera showing how the picture is taken and changed into a video signal.

inquiry. The pupils should find information similar to that which follows to help them understand how the image orthicon camera tube produces a video signal.

IMAGE ORTHICON CAMERA TUBE

Part	Function
1.* Object.	Scene before image orthicon camera.
2. Glass lens.	Focuses light reflected from object on phosphor coated screen called a *photocathode*. An inverted image is formed.
3. First image (inverted image).	Made up of areas that are very light and others that are less light.
4. Photocathode.	Has areas on it where the phosphors are receiving much reflected light from the object and other areas where the phosphors are receiving less light from the object. Phosphors react to the varying intensities of light energy by releasing larger and smaller bursts of electrons.
5. Larger and smaller bursts of electrons from photocathode.	Pass through screen (7) to target (6).
6. Target.	A neutral glass plate insulator 1/10,000 of an inch thick. The large and small bursts of released electrons strike the target. Where they strike, electrons from the target are knocked out; sometimes there are many and sometimes there are fewer. Where many are knocked out, a strong positive charge remains on the target; where fewer are forced out, a smaller positive charge is left.
7. Screen.	Carries away knocked out electrons.
8. Second image (target image).	Made up of positive charges of varying intensity.
9. Electron gun.	Shoots electron beam, which scans the intensity of the positive charges that make up the second image on the target.
10. Electron beam.	In the process of scanning the intensity of the positive charges on the target image, the beam loses just enough electrons to the positive charges on the target to neutralize it. The remaining electrons in the beam are attracted to and collected by the very strongly charged positive collector.
11. Collector.	An anode that collects the remainder of the beam, which is now fluctuating in intensity. Fluctuations are caused by loss of electrons to the target image. This fluctuating flow of electrons is the video signal.
12. Video signal.	The transmitter signal (carrier waves) that transmit the changes in the intensity of light that will produce an image of the object on a picture tube screen.

*Numbers correspond to those on Fig. 39.4.

The pupils should also find facts similar to the following to help them to build a better understanding of television camera tubes.

1. **There is more than one kind of television camera tube.**
2. **However, all kinds of television camera tubes are modified cathode ray tubes.**
3. **Broadcasting stations use two kinds of cathode ray tubes. The image orthicon is used to televise all programs except movie films. (See Fig. 39.4.) The iconoscope, which was formerly used to broadcast all programs, is only used when movies are televised.**
4. **Both kinds of television cameras contain an electron gun and a phosphor-coated screen.**
5. **The scanning beam in both cameras is controlled by deflection coils.**
6. **Both convert light energy to elecrical energy (the video signal).**

After the pupils have presented the information they obtained from reference books, find out whether they can apply it in their discussion of the diagram of the image orthicon. Questions similar to these could be used. (1) Why are the electrons repelled away from the phosphor screen? (They are repelled because the phosphor screen is a photocathode. It is connected to the negative electrode of the power supply. Whenever specks or dots of phosphor emit electrons, the phosphor tends to become positively charged. However, these dots immediately gain electrons from the negative electrode of the power supply to make up any deficiency.) (2) Which part of

Table 39.2

LIKENESSES AND DIFFERENCES BETWEEN A TELEVISION CAMERA TUBE (IMAGE ORTHICON) AND A TELEVISION PICTURE TUBE (KINESCOPE)

Likenesses	Differences
1. Both have tubes that are modified cathode ray tubes.	1. The image orthicon has *two screens*, a phosphor-coated screen and a target screen. The kinescope has only *one screen*, a phosphor-coated screen.
2. Both contain an electron gun, deflection coils, and a phosphor coated screen.	2. The image orthicon has two electron beams, the scanning beam and the return beam that is changed (modulated) by the photo electrons that strike the target screen. The kinescope has *only one electron beam*, the beam that scans the image on the phosphor-coated screen.
3. The scanning method for both is the same.	3. The image orthicon forms *two electron images;* one is visible and is formed on the phosphor-coated screen by the reflected light from the scene that is being televised, the other is invisible and is formed on the target screen when photo electrons from the phosphor-coated screen strike it. The kinescope forms *one electron image* on the phosphor-coated screen.
4. Both form an electron image on the phosphor-coated screen.	4. The image orthicon *converts the invisible electron image* on the target screen *into a video signal.* The kinescope *converts the video signal* into a *visible image* on the phosphor-coated screen.
	5. The image orthicon has *two cathodes,* the cathode of the electron gun and the photo cathode of the phosphor-coated screen. The kinescope has *one cathode,* the cathode of the electron gun.

the tube is the anode or positive electrode? (The collector.) (3) What prevents the electrons from the phosphors from moving to the collector? (They are attracted to the target, which is between the screen and the collector. The electrons emitted from the screen induce an opposite charge (positive) on the target.) (4) Why does the return electron beam not neutralize the positively charged collector? (The collector is connected to the positive electrode of the power supply.)

To help the pupils summarize the important facts about the image orthicon and compare it with the television picture tube, encourage them to organize the facts in a table similar to Table 39.2.

On the chalkboard, reproduce the block diagram shown in Fig. 39.5. Give the pupils time to study the information on it. Then ask questions like these to stimulate discussion. (1) What device in the transmitting circuit synchronizes the camera scanning beam and the scanning beam in the television picture tube? (The synchronizing generator.) (2) What method of modulation is used to combine the video signal and the carrier wave? (Amplitude modulation.) (3) How is the audio signal transmitted from the broadcasting station? (It is transmitted separately from the video signal. A television broadcasting station has two transmitters. One transmitter sends the audio signal on carrier waves and the second transmitter sends the video signal on carrier waves. These transmitters are synchronized so that the signals are transmitted simultaneously.) (4) What method of modulation is used to combine the audio signal with a carrier wave? (Frequency modulation.)

Check the depth of the students' understanding of the separate transmission of video and audio signals by their responses to situations like those that follow. (1) A television receiver occasionally loses its sound but continues to show a picture. Why is this possible? (The video and audio signals are transmitted on separate carrier waves. In this case, the video signal is being received, the audio signal it not.) (2) The speaker in the television set occasionally continues to reproduce the sounds of a television program without a picture. How does this happen? (The broadcasting station is probably having trouble with the video signal transmitter.) (3) Why do these two different experiences provide evidence that audio waves and video waves are transmitted separately? (If the audio and video signals were

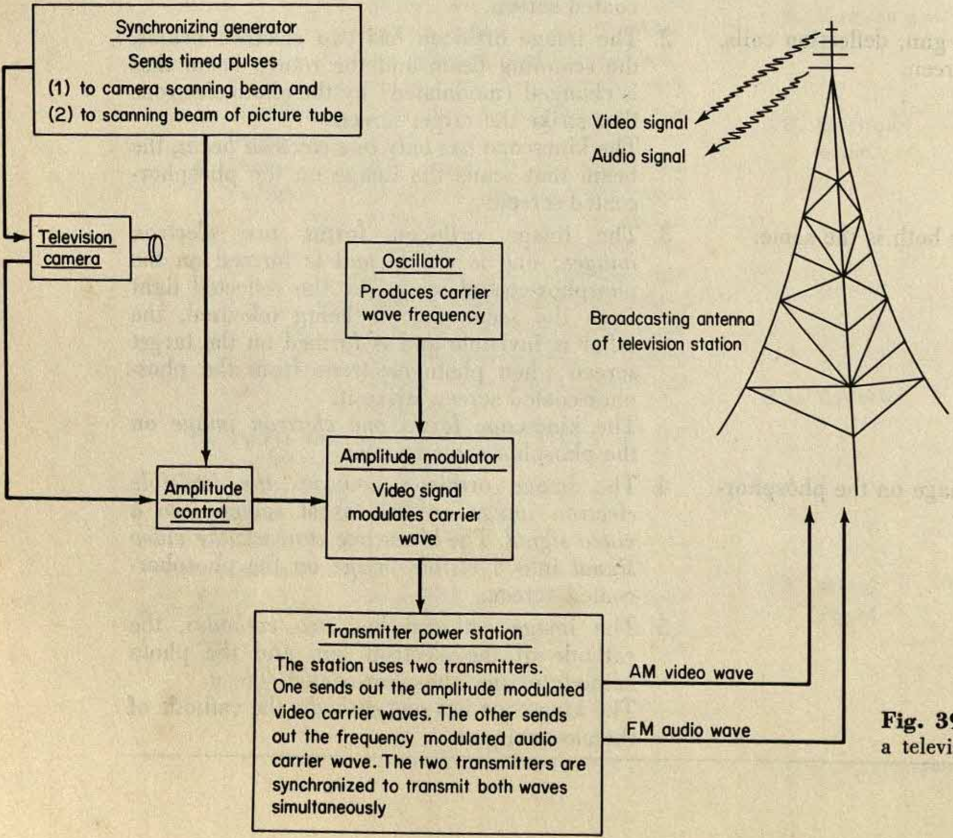

Synchronizing generator
Sends timed pulses
(1) to camera scanning beam and
(2) to scanning beam of picture tube
Video signal
Audio signal
Television camera
Oscillator
Produces carrier wave frequency
Broadcasting antenna of television station
Amplitude control
Amplitude modulator
Video signal modulates carrier wave
Transmitter power station
The station uses two transmitters. One sends out the amplitude modulated video carrier waves. The other sends out the frequency modulated audio carrier wave. The two transmitters are synchronized to transmit both waves simultaneously
AM video wave
FM audio wave

Fig. 39.5 Modified block diagram of a television transmitting circuit.

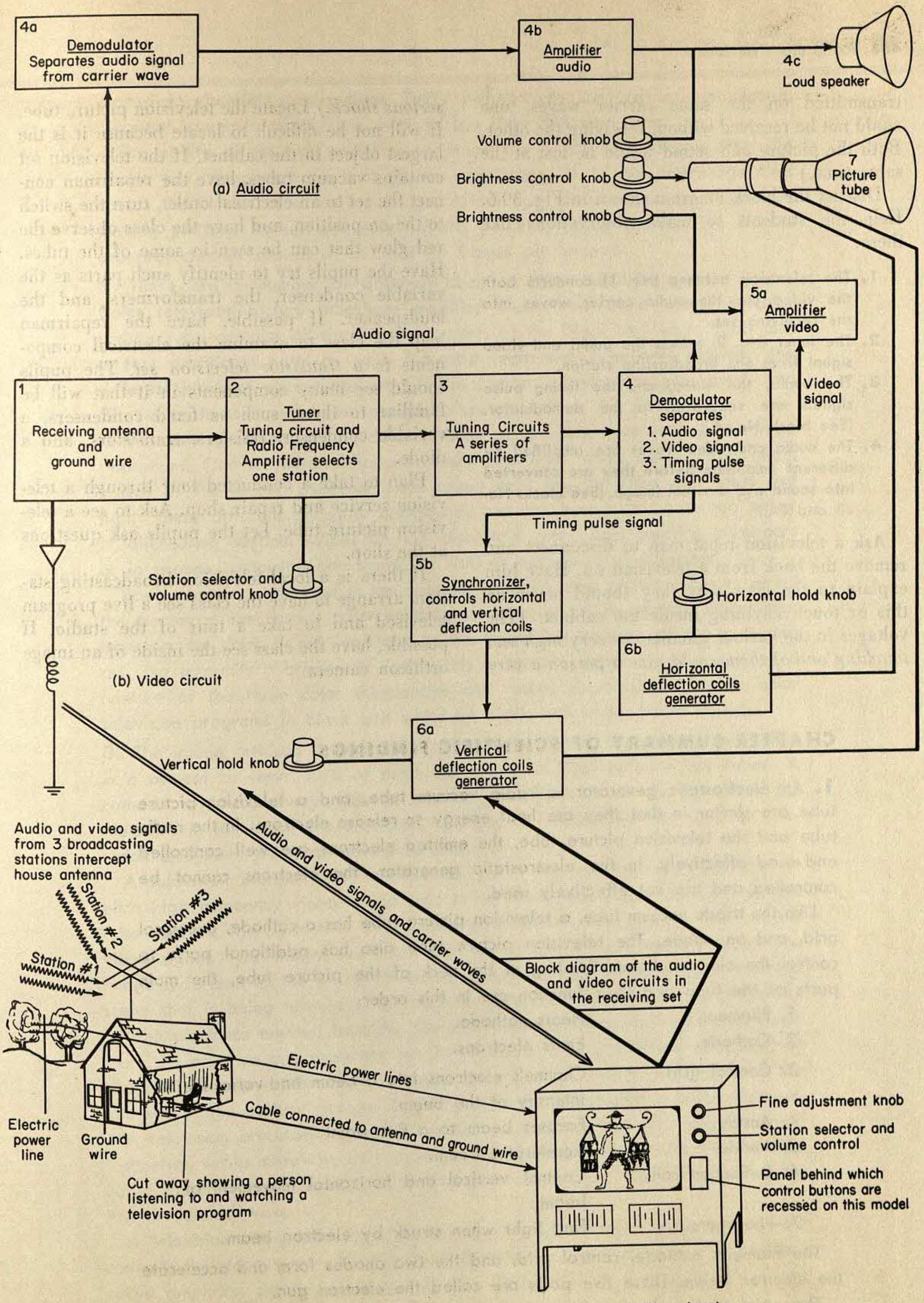

4a
Demodulator
Separates audio signal from carrier wave
4b
Amplifier audio
4c
Loud speaker
Volume control knob
Brightness control knob
Brightness control knob
7
Picture tube
(a) Audio circuit
5a
Amplifier video
Audio signal
1
Receiving antenna and ground wire
2
Tuner
Tuning circuit and Radio Frequency Amplifier selects one station
3
Tuning Circuits
A series of amplifiers
4
Demodulator
separates
1. Audio signal
2. Video signal
3. Timing pulse signals
Video signal
Timing pulse signal
5b
Synchronizer, controls horizontal and vertical deflection coils
Station selector and volume control knob
Horizontal hold knob
6b
Horizontal deflection coils generator
(b) Video circuit
6a
Vertical deflection coils generator
Vertical hold knob
Audio and video signals from 3 broadcasting stations intercept house antenna
Station #2
Station #3
Station #1
Audio and video signals and carrier waves
Block diagram of the audio and video circuits in the receiving set
Electric power lines
Cable connected to antenna and ground wire
Fine adjustment knob
Station selector and volume control
Panel behind which control buttons are recessed on this model
Electric power line
Ground wire
Cut away showing a person listening to and watching a television program

Fig. 39.6 Modified block diagram of a television receiving circuit.

transmitted on the same carrier waves, one could not be received without receiving the other. Both the picture and sound would be lost at the same time.)

Discuss the block diagram shown in Fig. 39.6. Help the students to make observations like these:

1. The television antenna (No. 1) conducts both the video and the audio carrier waves into the receiving set.
2. The tuner (No. 2) *selects* the audio and video signal from *one broadcasting station.*
3. The audio, the video, and the timing pulse signals are separated in the demodulator. (See block No. 4.)
4. The audio and video waves are amplified by different amplifiers before they are converted into sound and a visual image. (See blocks No. 4B and 5A.)

Ask a television repairman to disconnect and remove the back from a television set. Have him explain to the class why they should never do this or touch anything inside the cabinet. (The voltages in the various circuits *are very high and touching one of them could give a person a very serious shock.*) Locate the television picture tube. It will not be difficult to locate because it is the largest object in the cabinet. If the television set contains vacuum tubes, have the repairman connect the set to an electrical outlet, turn the switch to the *on* position, and have the class observe the red glow that can be seen in some of the tubes. Have the pupils try to identify such parts as the variable condenser, the transformers, and the loudspeaker. If possible, have the repairman help the class to examine the electrical components *in a transistor television set.* The pupils should see many components in it that will be familiar to them, such as fixed condensers, a variable condenser, resistors, transistors, and a diode.

Plan to take a conducted tour through a television service and repair shop. Ask to see a television picture tube. Let the pupils ask questions at the shop.

If there is a local television broadcasting station, arrange to have the class see a live program televised and to take a tour of the studio. If possible, have the class see the inside of an image orthicon camera.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. An electrostatic generator, a radio vacuum tube, and a television picture tube are similar in that they use heat energy to release electrons. In the radio tube and the television picture tube, the emitted electrons are well controlled and used effectively. In the electrostatic generator, the electrons cannot be controlled and are not effectively used.

Like the triode vacuum tube, a television picture tube has a cathode, a control grid, and an anode. The television picture tube also has additional parts to control the electron beam. Starting at the neck of the picture tube, the main parts of the tube and their function are in this order:

1. Filament.	Heats cathode.
2. Cathode.	Emits electrons.
3. Control grid.	Channels electrons *into a beam* and *varies the intensity* of the beam.
4. Anode.	Focuses beam to a fine point.
5. Anode.	Accelerates beam.
6. Deflection coils.	Control vertical and horizontal movement of beam.
7. Phosphors.	Emit light when struck by electron beam.

The filament, cathode, control grid, and the two anodes form and accelerate the electron beam. These five parts are called the *electron gun.*

The point of the electron beam scans the screen 525 times in 1/30th of a second to complete one picture. Thirty pictures are scanned in one second. European countries usually use more or less than 525 scan lines.

The ability of the eye to retain an image for 1/16th of a second after the image has disappeared is called the *afterimage*. It is the afterimage that causes the illusion of a moving image. Afterimages also explain the illusion of moving pictures from a sequence of still pictures, called frames. The frames are projected at speeds of at least 16 frames per second.

2. There are a number of different kinds of color television picture tubes. Color television picture tubes are modified black and white tubes. A color picture tube contains all the important parts of the black and white tube and a few additional parts as well. The most important differences between the different kinds of color tubes are (1) the number of electron guns used, and (2) the patterns in which the phosphors are coated on the screen.

The viewing screens of the different color picture tubes are coated with three phosphors. One of these compounds emits blue light when the electron beam strikes it. The second phosphor emits green light and the third one emits red light. These different phosphor compounds are distributed on the screen either in alternating vertical stripes of red, blue, and green light emitting phosphors or in groups containing one speck, or dot, of each kind of phosphor.

Special devices are used in the different kinds of color picture tubes to direct the beams to the correct color emitting stripe or dot. The picture signal that transmits the color signal sequence to the television antenna of the receiving set also transmits a brightness signal. This brightness signal is composed of a mixture of the three color frequencies and makes it possible to view color television programs in black and white on *black and white picture screens.*

3. The image orthicon camera tube and the television picture tube are alike in a number of ways. Both of these tubes are modified cathode ray tubes. A cathode ray tube always has an electron gun and an anode to which the electrons in the beam are attracted. Cathode ray tubes that are used in television also have phosphor-coated screens.

A television picture tube contains the parts that are necessary to convert ultra high frequency video waves into visible light. An image orthicon camera tube contains the parts that are necessary to convert the scene it "*sees*" into a video signal. Two images are formed in the image orthicon camera tube. One image is formed on the phosphor-coated screen by the reflected light from the scene that is being televised. The second image is formed on the target screen by the electrons emitted from the phosphor-coated screen. As the electron beam from the electron gun scans the target image, it returns a beam composed of electrical impulses (the video signal), which are in direct proportion to the intensity of the positive charges in that part of the image that is being scanned.

A television broadcasting station has two transmitters that send two ultra high frequency waves simultaneously. One carries the video signal and the other the audio signal. The audio wave is an FM modulated wave; the video wave, an AM modulated wave.

A television set contains two circuits. One circuit amplifies, demodulates, and converts the video wave into a visible image on the viewing screen. The second circuit amplifies, demodulates, and converts the audio wave into audible sound waves.

Chapter Forty

Radar, Maser, and Laser

INQUIRIES

1. What is radar? How is radar used? How does radar work?
2. What is a maser beam? What is a laser beam? What can they do? What is the future for both?

1. What is radar? How is radar used? How does radar work?

Most pupils have some general knowledge about radar. Explore the extent of their knowledge. It will probably contain most of these concepts.

1. **Radar is used to locate such objects as ships, planes, missiles, satellites, clouds, coastlines, and mountains.**
2. **Planes use radar in many ways. Radar is used to scan the area ahead of a plane for clouds containing precipitation, for mountains, and for other planes. It also shows the pilot how high the plane is above the earth's surface. Airports use radar to track approaching planes and to assist them to make a safe landing. Bombers use radar to locate such targets as cities, harbors, and so on. With radar, fighter planes locate and destroy the enemy.**
3. **Radar is used to protect many countries from a surprise enemy attack.**
4. **Radar is used to track satellites and spacecraft.**

5. **The word *radar* was formed from parts of words which describe its function. *Radio* (RA) waves are used to *detect* (D) the direction and determine the *range* (AR) of objects.**
6. **A radar set both transmits and receives radio signals. It receives that part of its transmitted wave which is reflected back to it. The wave received is a radio echo of the transmitted wave.**
7. **Radar is a way of seeing the image of distant objects on a phosphor-coated screen. The reflected wave received by radar is make visible on a radarscope, which, like a television picture tube, is a kind of phosphor coated cathode ray tube.**

Use enlargements of the two block diagrams in Fig. 40.1 to show that radar is both a transmitter and a receiver of radio waves. Trace the flow of current in the transmitting circuit and then in the receiving circuit. Discuss how the circuits operate at different times. (When the radio wave is being transmitted, the receiving circuit is opened. When the radio echo is being received, the transmitting circuit must not be allowed to transmit.)

The opening and closing of the two circuits are controlled by the electronic timer. Why is an *electronic* timer necessary for the operation of the switches in the two circuits? To help the pupils answer this last question, work with them step by step, through the discussions that follow.

Ask the pupils to figure how much time would elapse between the sending and receiving of the radio waves sent by radar, if the object that reflects the waves is 93,000 miles away. (A radar pulse *traveling to* and *returning from* an object 93,000 miles distant would travel 186,000 miles. Because all electromagnetic waves, which include the waves sent out by radar, travel at 186,000 miles per second, it would take radar *one second* to report this object.)

Three facts are clear. (1) Radar is used *to locate many objects less distant than 93,000 miles.* (2) *Radar echoes* from objects *nearer than 93,000 miles* would return *in less than one second.* (3) *A unit of time smaller than one second is needed for nearer objects.*

The unit of time selected for radar is a *microsecond.* One microsecond is *one millionth of a second.* How far will the radar wave travel in one microsecond? (186,000 divided by 1,000,000 = 0.186 miles per microsecond.) How many feet is 0.186 miles? (5280 multiplied by 0.186 = 982 feet.) How many feet will a radar wave travel in one microsecond? (982 feet per microsecond.)

How much time will it take a radar wave to locate a target 150 feet away? (The wave will travel 300 feet; 150 feet to the target and 150 feet back to the radar. If the wave can go 982 feet in one microsecond, it will report targets as near as 150 feet distant *in less than one microsecond.* 300 divided by 983 = 0.30 microseconds.) If radar is to report targets as near as 150 feet, *how long can the transmitter be allowed to operate* and still pick up the return pulse 0.30 microseconds later? (The transmitter must operate less than 0.30 of a microsecond, because it must not be transmitting when the return pulse is received. A pulse lasting 0.25 or ¼ of a microsecond would permit the radar antenna to receive the returning signal 0.30 of a microsecond later.)

Radar waves are limited to about 40 or 50 miles by the curvature of the earth. How many microseconds would it take a radar pulse to report a ship at a distance of 40 miles? (Radar waves travel 0.186 miles per microsecond. To report a target 40 miles distant, the waves would travel 80 miles. 80 divided by 0.186 = 430 microseconds.)

In order for radar to locate targets between 150 feet and 40 miles, for how long should the pulse be transmitted? (About ¼ of a microsecond.) How much elapsed time must there be between pulses? (About 430 microseconds.) To accomplish this, the radar would be timed to transmit for ¼ of a microsecond and to receive for 430 microseconds and then to repeat the cycle over and over again.)

If a radar circuit is adjusted to report objects in the *atmosphere* at distances to 300 miles, would its period of receiving be longer or shorter than 430 microseconds? (Longer.) How long? (600 divided by 0.186 = approximately 3226 microseconds.)

Show the pupils how to operate a stopwatch. Have them start and stop it is *as rapidly as they can.* Record how fast it can be done. Was anyone able to start and stop it in 1/50, 1/20, or 1/10 of a second? Change the fastest recorded time into microseconds. (1/50 multiplied by 1,000,000 = 20,000 microseconds.) Compare the fastest manual speed (in microseconds) with the need for some radar circuits to be timed to switch the transmitter on and off in ¼ of a microsecond.

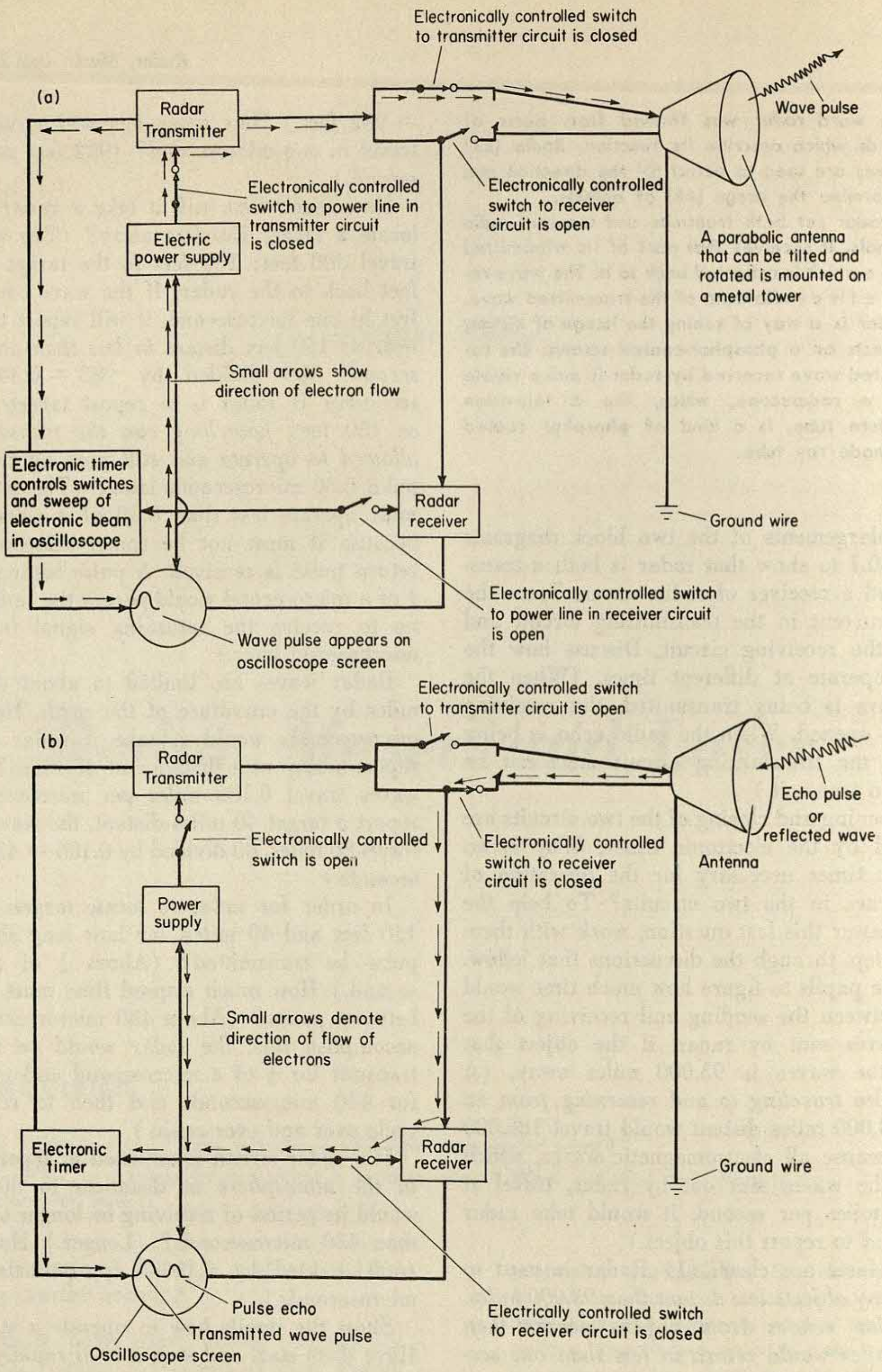

Electronically controlled switch to transmitter circuit is closed
(a)
Radar Transmitter
Wave pulse
Electronically controlled switch to power line in transmitter circuit is closed
Electronically controlled switch to receiver circuit is open
Electric power supply
A parabolic antenna that can be tilted and rotated is mounted on a metal tower
Small arrows show direction of electron flow
Electronic timer controls switches and sweep of electronic beam in oscilloscope
Radar receiver
Ground wire
Electronically controlled switch to power line in receiver circuit is open
Wave pulse appears on oscilloscope screen
Electronically controlled switch to transmitter circuit is open
(b)
Radar Transmitter
Echo pulse or reflected wave
Electronically controlled switch is open
Electronically controlled switch to receiver circuit is closed
Antenna
Power supply
Small arrows denote direction of flow of electrons
Electronic timer
Radar receiver
Ground wire
Pulse echo
Transmitted wave pulse
Oscilloscope screen
Electrically controlled switch to receiver circuit is closed

Fig. 40.1 Block diagrams showing a radar transmitter circuit (a) and a radar receiver circuit (b). In (a) the transmitter circuit is closed and the receiver circuit is open during transmission of the wave pulse (radio signal). The electronic timer synchronizes the transmission of the signal with the electron beam in the oscilloscope so that the signal and the appearance of the signal pulse on the screen occur simultaneously. In (b) the electronic timer opens the transmitter circuit and closes the receiver circuit as soon as the wave pulse is "sent out" from the antenna. These electronic controls make it possible to use the same antenna for transmitting signals and receiving the reflected pulse or echo.

Help them to conclude that only an *electronic timer* can work at such speeds.

If radar is beamed to the moon, how long will it take for the radar pulse to travel to the moon and return? (Use the round figure of 240,000 miles for the distance to the moon. 480,000 divided by 186,000 = 2.5 seconds.)

If radar is beamed to the sun (round figure distance 93,000,000 miles), how long will it take the radar pulse to travel to the sun and return? (186,000,000 divided by 186,000 = 1000 seconds. How many minutes is 1000 seconds? (1000 divided by 60 = 16.66 minutes.)

Help the pupils to make a list of further information they would like to obtain about radar. If the following information is not asked for by them, add these questions to the list. Assign one or more questions to different members of the class and have them use text and reference books to locate the information.

1. What are Some of the Differences Between a Black and White Television Viewing Screen and the Oscilloscope Viewing Screens That Are Used in Radar? There are several differences. (1) The radar screen is coated with a phosphor that emits light *for a longer period of time* than does the phosphor on the television screen. (2) A television viewing screen converts a video signal into a visible image of the scene that is being televised. This video signal is carried by *ultra high frequency* carrier waves to the television receiver. A radar transmitter sends pulses of radio *microwaves*. The transmitted pulse and the echo pulse are converted into visible light on the radarscope. (3) Television screens differ from each other mainly in size and shape. There are a number of different kinds of radar oscilloscope screens. The kind of screen used depends upon the purpose for which the scope is to be used. Some of the scales on these scopes are calibrated to measure distances in yards and others are calibrated in miles. Some are calibrated to measure both direction and distance. Still others are calibrated to show direction and altitude. (See Figs. 40.2, 40.3, and 40.4.) the method used to scan the phosphor-coated screens in different makes of black and white television receivers is the same. Several different methods are used to scan the screens in different kinds of radar oscilloscopes. Three of these methods are shown in Figs. 40.2, 40.3, and 40.4. In preparation for a discussion of these figures, appoint several children to locate pictures of the three types of screens. Have them drawn for study and discussion on the chalkboard. In Fig. 40.2, the electron beam appears to sweep across the oscilloscope screen from left to right in what seems to be a *straight line* of light. Actually this line is *an illusion*. As the electron beam moves across the screen, it causes small specks or dots of phosphor to emit light. Because the deflection coils in the cathode ray tube are connected to both the radar's transmitter and the receiver, the transmitted pulse and the echo pulse both appear as small deflections in this line of light on the screen. The radar screen in Fig. 40.2 is calibrated in inches, microseconds, and miles. One inch is equivalent to 100 microseconds and to 9.3 miles. The range distance of the object that caused the echo pulse can thus be read directly from the screen in miles. Next study the radar screen shown in Fig. 40.3. This plan position indicator (PPI) radarscope gives a view of the *scanned* area as one would see it if one were looking down upon it. The PPI scope's electron beam traces a line of light from the center of the screen to the outer edge. When this light trace reaches the outer edge of the screen, it returns to the center and repeats the procedure until it has swept the entire 360 degrees of the circular screen. A complete sweep of the screen is completed every 400 microseconds. The circular

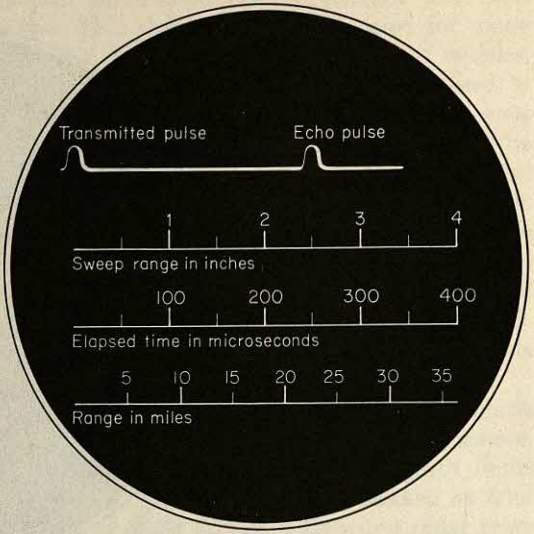


Fig. 40.2 Radarscope calibrated to show range in microseconds and in miles.

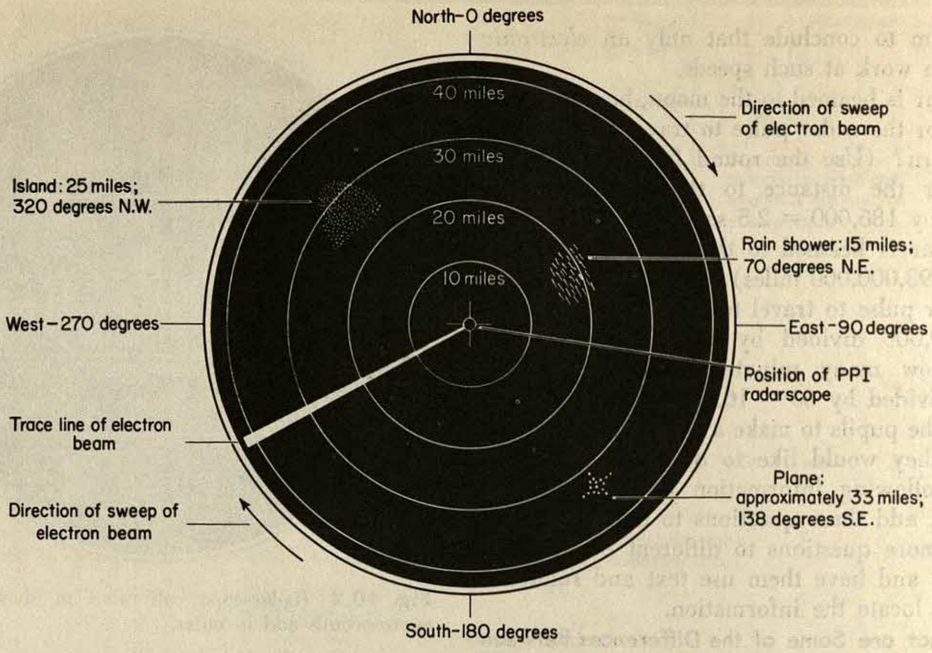
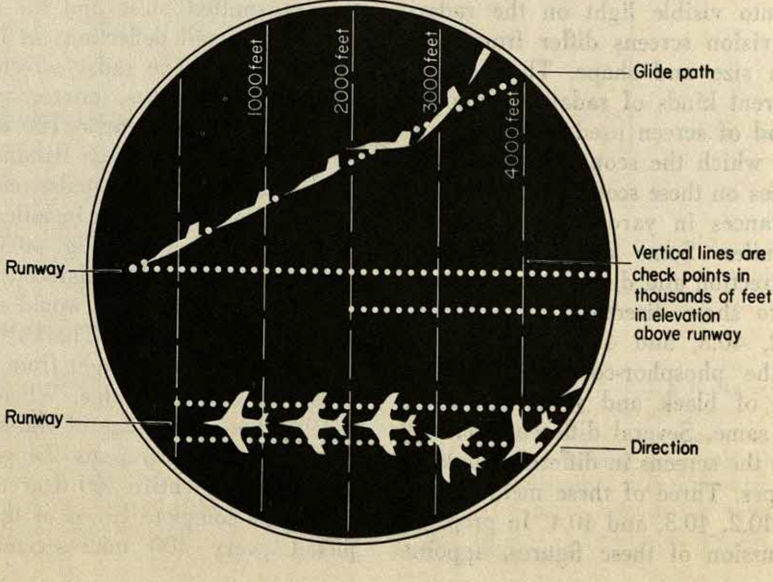

North–0 degrees
40 miles
30 miles
20 miles
10 miles
Direction of sweep of electron beam
Island: 25 miles; 320 degrees N.W.
Rain shower: 15 miles; 70 degrees N.E.
West – 270 degrees
East – 90 degrees
Position of PPI radarscope
Trace line of electron beam
Plane: approximately 33 miles; 138 degrees S.E.
Direction of sweep of electron beam
South–180 degrees

Fig. 40.3 A plan position indicator (PPI) radarscope (scans area).

sweep of the electron beam over the radarscope is synchronized with the sweep of the PPI radar antenna. Radio waves, reflected from objects located by the transmitted pulse, produce an electron image of the object on the radarscope. The object's identity, distance, and direction show on the radarscope. The PPI scope is used for mapping land, sea, and sky areas. This kind

Fig. 40.4 A range height indicator (RHI) radarscope. This final part of a ground controlled approach (GCA) system is used to simultaneously monitor the approach direction and the glide path of a plane that is landing on an airfield.


1000 feet
2000 feet
3000 feet
4000 feet
Glide path
Runway
Vertical lines are check points in thousands of feet in elevation above runway
Runway
Direction

of scope is also used by ships at sea and by meteorologists, who are locating regions in which storms are occurring. Radar operators in airports use a PPI scope with a range of 0 to 100 miles to sight planes when they enter the scanning area of this search scope. This is the first part of the ground controlled approach (GCA) system used by airports.

Finally study the radarscope in Fig. 40.4. This type of screen is called a range height indicator (RHI). It is a precision control screen used in the final part of the ground controlled approach (GCA) system used by airports. This scope is used by radar operators at airports to talk pilots (1) into the precise direction of the runway, and (2) down the exact glide path to a safe landing on the runway. This electron beam sweeps the scope from right to left. It is also possible for the scope to send the information about direction and altitude back into an electronic computor on the plane. The computer can then land the plane without the pilot's help.

2. How Do Radio Waves Transmitted by Radar Differ from the Radio Waves That Are Transmitted by Radio and Television Broadcasting Stations? Radar waves are much shorter than the radio waves sent out by either radio or television transmitters. The waves transmitted by radar are called *microwaves. Micro* means millionths of a meter. Microwaves are 1 millimeter or less in length. Some radar stations transmit microwaves that may be only 300/1,000,000 of a meter in length. Radio and television transmitters send out *continuous radio waves.* A radar transmitter sends out *bursts (short pulses)* of radio microwaves.

3. Why Are Radio Microwaves Used for Tracking Distant Objects Instead of the Ultra High and High Frequency Radio Waves? There are three reasons. (1) Longer wave lengths bend around (are diffracted) objects. Microwaves are not diffracted. They bounce back from, or are reflected by, the object they strike. (2) Microwaves can be focused into a narrow beam. This aids in reflection. (3) Microwaves penetrate greater distances into space than either high or ultra high frequency waves.

4. What Are Some of the Different Shapes of Antennas That Are Used for Transmitting And Receiving Radar Signals? For What Purpose Are They Used? A *parabolic* or saucer shaped antenna is used to focus the outgoing and incoming radar pulses. Microwaves can be focused like light waves. This shape of antenna is used for many purposes, such as tracking planes, missiles, rockets, satellites, and ships. It is also used to observe cloud formations and to track storms. The parabolic antenna is mounted so it can be rotated. It also can be made to sweep up and down as it rotates. Some of the largest parabolic antennas rotate on tracks that are built on the ground. Another type of radar antenna is shaped somewhat like the television antennas mounted on house roofs. This type is being used for transmitting and receiving radar pulses from objects millions of miles in space.

5. How Far Can a Radar Station Track Objects That Are Either on the Earth, in the Atmosphere, or in Space? The curvature of the earth limits the distance that objects can be tracked *on land and sea* to about 50 miles. By using radar relay stations that are built about 50 miles apart, it would be possible to track objects in all parts of the earth. Radar can be used to track objects as distant as 300 miles *in the atmosphere.* Radar waves can be made to travel many millions of miles *into our solar system* by using very specialized electronic equipment and antennas. Radar waves have been reflected from such bodies in our solar system as the sun, the moon, and Venus. It is known that microwaves have the energy necessary to travel many light years *into space,* because microwaves are being constantly received from space. Certain stars called radio stars and certain regions in space, where no stars have been discovered by optical telescopes, emit microwaves, which are received by radio telescopes.

2. What is a maser beam? What is a laser beam? What can they do? What is the future for both?

Masers have extended the ability of receivers *to amplify very weak microwaves.* Ask the pupils to read and report to the class about the use of masers in clocks, in radio telescopes, and in space communications.

The word *maser* was derived from the first letters of the following words: *microwave amplification* by *stimulated emissions* of *radiations.*

Without the ability of masers to amplify microwaves, the space age would be limited in the distances through which it could send and receive messages. Have the pupils read about the giant antenna built by Bell Telephone Laboratories at Andover, Maine to send and receive communications from overseas by a relay station on the satellite Telstar. Also have the pupils read about the communication satellites which make worldwide television and communication possible. Discuss why each of these satellites must be in a synchronous orbit. Discuss how masers made it possible to receive the televised pictures of the moon's surface and the pictures of Mars. Also, discuss the role masers will have in making possible communication with astronauts on a trip to the moon.

The word *laser* was formed from *light amplification* by *stimulated emissions* of *radiation.* Some pupils very likely will have seen television demonstrations of a laser beam's ability to cut through steel or will have read about how a beam of red light from a laser was sent to the moon and reflected from the moon back to the earth.

Ask some interested student to explore the characteristics of the *coherent light* emitted by lasers and report to the class. (The high, ultra high, and microwave frequencies used by radio, television, and radar are *coherent radiations.* Coherent means that they are powerful, free of noise, and can be generated on a specified frequency of *a single wave length.* Because white light is a mixture of wave lengths, it is not coherent light. Prior to laser, any colored light also contained too many wave lengths to be coherent. Because a laser produces colored light of a *single wave length,* it is a coherent radiation which is both powerful and noiseless. Like coherent radiation now used to carry radio, television, and radar information, the coherent radiation from lasers can be used to carry similar signals. Like microwave radiation, the narrow beam of coherent laser radiation can be focused to an even narrower and more powerful beam.)

Have the pupils investigate and report on the present uses and some of the possible future uses of laser. These should include their use as a surgical tool, as weapons of defense, and as means of communication. The laser, by producing shorter wave lengths of visible light, has added new wave lengths to the crowded radiation bands now used for communication.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Radar is used to detect and to determine the range of objects. A radar system is a combination of a radio transmitter and receiver *with an added cathode ray tube* on which a picture is electronically sketched. Radar waves are much shorter than the waves used by radio and television transmitters. The waves transmitted by radar are called microwaves. A radar station sends bursts or short pulses of microwaves. When microwaves strike an object, they are reflected. Microwaves can be focused in the same way that visible light waves can be focused.

The primary purpose of radar is to measure the time lapse between the transmitted pulse and the return pulse or echo. A microsecond is used to determine the range of objects in the atmosphere and on the surface of the earth. A microsecond is 1/1,000,000 of a second.

There are a number of different kinds of radar oscilloscope screens. The kind of radar oscilloscope screen that is used in a receiving set depends upon the purpose for which the radar is used.

The curvature of the earth limits the distance that objects can be tracked on the earth. The range of a radar system is much greater in the atmosphere than it is on the earth's surface. Radar signals (microwaves) have been transmitted to a number of the heavenly bodies in the solar system, and reflected from them.

Radar systems are used for many purposes. Some of the purposes for which radar is used are to track missiles, planes, rockets, and artificial satellites, as well as to guide planes to the runways on airfields. Radar is also used to track storms.

2. Maser and laser beams add new dimensions to long distance communication. Masers amplify the very weak microwaves that travel very long distances. Laser beams are a powerful coherent light source, whose radiations are even shorter than the microwave radiations used by radar. Both maser and laser beams are tools of and for the space age.

Chapter Forty-One

Global and Spatial Electronic Communication

INQUIRIES

1. How can unmanned spacecraft be made to collect and send information to earth through millions of miles of space?

2. Why can low frequency waves be transmitted for greater distances on the earth's surface than ultra high frequency waves and microwaves?

3. Who are some of the scientists who have made important contributions in the development of electronic communications? What contributions did they make? Why have not all scientists who have made important discoveries and inventions during the past 25 years been given recognition for their individual contributions?

4. What advances have been made in communications in the last decade? What are some of the advances predicted for the next decade?

1. How can unmanned spacecraft be made to collect and send information to earth through millions of miles of space?

The system used is called *telemetry*. Different electrical circuits in the spacecraft are *programmed* to transmit *coded microwave pulses* (pulses that differ in the length of time in which they are transmitted) from the spacecraft to a receiving station on the earth. This kind of system requires one or more transmitters in the spacecraft.

Telemetry is very similar to a radio broadcast.

The microphone converts the data into electrical impulses that are combined with a radio carrier wave of an assigned frequency. The carrier wave transmits the electrical impulses to the receiver. When the receiver is tuned to the broadcast frequency, the signal enters the set. The receiver then amplifies, separates the signal from the carrier wave (demodulates), and converts it into information. Both the transmitter in the spacecraft and the receiving station on the ground *must be tuned to the same frequency.*

This is a simple example of how an unmanned spacecraft can collect and transmit information. For example, assume that a micrometeorite (a very small meteor) strikes the coating on the outside surface of the spacecraft. If the impact is large enough to register on the electrical circuit that is connected from the coating to the transmitter inside the spacecraft, the transmitter will emit a signal. This signal will be detected by the receiving station on the earth. The signal also will be automatically recorded on magnetic tape in the receiving station. In this example, the spacecraft is said *to be programmed* to report strikes by micrometeorites. The spacecraft may also be programmed for many other experiments. Each experiment that is programmed for a spacecraft makes a different code mark on the tape.

Some spacecraft are equipped with on-board tape recorders. As each experiment is carried out by the different electrical circuits, the data are recorded on this tape and stored until the spacecraft is within the range of a receiving station on the earth. A radio signal (command) is transmitted by the station to the spacecraft. When the signal is detected by the receiver on the spacecraft, the circuit of the on-board tape recorder is automatically closed and the coded signals recorded earlier on its tape are transmitted to the receiving station on the earth. If there is more than one tape recorder in the spacecraft, the station can *command* circuits of anyone or all of the recorders to close and transmit the information stored on the tape.

Television is also used in some spacecraft-to-earth communications systems. The first photographs of cloud cover above the earth and the pictures of the moon and Venus were obtained by this kind of communications system. The image of the picture is stored on video tape and converted into electrical impulses by the transmitter in the spacecraft when a command signal is received from the station on the earth. The television station on the earth unscrambles the electrical impulses and records them on video tape. On the Apollo flights, the earth received television broadcasts directly.

Help the pupils to organize the important facts they have learned into simple, concise statements. Also encourage them to use these statements and the new vocabulary that has been developed.

2. Why can low frequency waves be transmitted for greater distances on the earth's surface than ultra high frequency waves and microwaves?

Children may know that they can *pick up* radio programs from a greater distance at night than they can in the daytime. What causes this difference in the range (distance) in which radio programs can be transmitted? There is a region in the upper atmosphere that *reflects* some frequencies of radio waves back to the earth. This region is called the *ionosphere.*

Stress the importance of consulting more than one classification or title in book indexes when searching for information. For example, it would be very useful to know that another name for the ionosphere is the *Kennelley-Heaviside Layer.* Ask the pupils to list all the different words they can consult in an index when they are searching for information about the ionosphere. (Ionosphere, ionize, air, atmosphere, and the *Kennelley-Heaviside Layer.*)

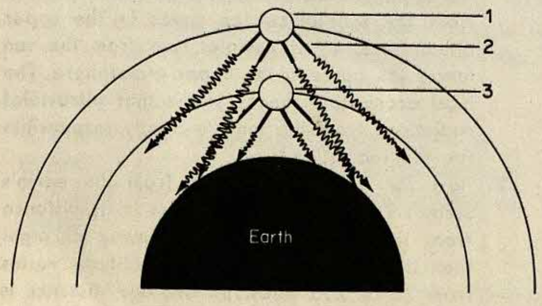
Also have the class help to list questions similar to the following ones, which can be used to guide them in their search for information.

1. What causes the region of the atmosphere, called the ionosphere, to become ionized? (There are several theories. Three of them are as follows: (1) High speed electrons from the sun knock electrons free from the gases in the upper atmosphere. (2) High speed protons from the sun ionize the gases in the upper atmosphere. (3) Ultraviolet rays from the sun ionize the gases in the upper atmosphere. The most acceptable theory states that ultraviolet radiations from the sun are chiefly responsible for the ionization.)
2. How far is the ionosphere from the earth's surface? (The ionosphere varies in its distance from the earth. It is farther away at night than it is in the daytime. Its altitude varies from 20 to 250 miles. Its average distance is approximately 70 miles.)

3. What changes occur in this ionized region that make it possible for radio waves to be transmitted for greater distances at night than in the daytime? [Before assigning reference work on this question, discuss some of the previous experiences that the pupils have had which should enable them to make informed guesses regarding the answer. In Chap. 35, Inquiry 6, experiences were suggested to develop the understanding that the sun emits electromagnetic waves that range in frequency from the lowest frequencies (electric waves) to the highest frequencies (cosmic rays). (See Table 35.4.) Ultraviolet waves are emitted by the sun. In the daytime some of these rays pass through the atmosphere and strike the earth's surface. If ultraviolet radiations cause ionization, it may be that the ionosphere is nearer the earth's surface in the daytime than it is at night.]

What effect would the change in altitude of the ionosphere have on the distance that radio waves can be transmitted? (This question can be answered by studying Fig. 41.1. Draw on the chalkboard a semicircle representing the earth and an artificial satellite that orbits the earth at a distance of 100 miles. Also draw the wavy lines that represent the radio waves that are being relayed to the earth from the satellite's antenna. Have the pupils *predict* whether a second satellite placed in orbit at a distance of 200 miles would relay radio waves to a smaller or a larger area on the earth. After they have made their *predictions,* ask one of the pupils to draw a second satellite as shown in Fig. 41.1. Apply this experience to the pupils' assumption that the ionosphere is nearer the earth's surface in the daytime than it is at night. The assumption seems to be a reasonable one. Why? (Radio waves are transmitted greater distances at night than they are in the daytime.)

Fig. 41.1 Relationship of satellite orbit and radio wave transmission coverage. A satellite in a larger orbit (1) transmits radio waves via its antennas (2) to more of the earth's surface than does the satellite in a smaller (lower) orbit (3).



Develop an awareness that there may be *a number of changes in both the composition and height of the ionosphere* that cause the difference between day and night radio reception by making the following statement. "Radio signals *are stronger at night* than they are in the daytime." Why can the stronger night signal not be accounted for by the increased height of the ionosphere at night? (The radio signal travels farther. The signal should be weaker at night because the farther a signal travels, the weaker it becomes.)

Refer the class to question 3. Emphasize *the need* for *restating this question* so that it will incorporate these two known facts: (1) Radio signals can be transmitted *greater distances* at night than they can in the daytime. (2) Radio signals are *stronger* at night than they are in the daytime. This is one way question 3 could be restated: What changes occur in the ionosphere at night that *improve* radio reception?

The information necessary to answer questions 1 and 2 is included in the discussion of those questions. The following paragraphs contain further facts that also are needed to answer question 3 fully.

The sun's radiations partially ionize the upper atmosphere by knocking millions of electrons from its rarified gases. This partially ionized upper atmosphere is called the ionosphere. When *high frequency* radio waves strike the lower part of the ionosphere, they *set up secondary* radio waves of the same frequency in the partially ionized gases. Because some of these secondary waves are transmitted back to earth, the ionosphere *is said to reflect* radio waves back to earth. Actually, the radio waves transmitted by the broadcasting station are not bounced back to the earth in the same way that a mirror reflects light. It is the new radio waves, or secondary waves, formed in this part of the ionosphere, which return to the earth. These secondary radio waves are often referred to as *skywaves* to distinguish them from the *ground waves* that travel directly from broadcasting antenna to receiving set antennas.

In the daytime the ionosphere contains three layers. The lowest layer is called the *D layer.*

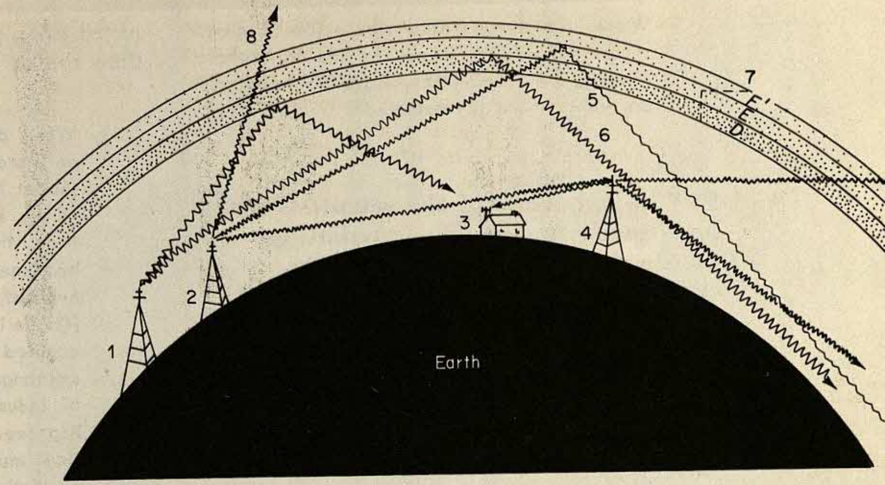


Fig. 41.2 The effects of the daytime structure of the ionosphere on radio and television wave transmission. (1) Radio broadcasting station aerial; (2) TV broadcasting station aerial; (3) home receiving set aerial; (4) TV relay station aerial; (5) UHF television waves; (6) high frequency radio waves; (7) ionized layers in upper atmosphere in the daytime; (8) microwaves.

The layer above the *D layer* is called the *E layer* and the highest layer is called the *F^1 layer*. (See Fig. 41.2.) During the daytime, radiation from the sun ionizes all three layers of the ionosphere. At night the three layers combine into one high ionized layer called the *F^2 layer*.

In the daytime, wave frequencies between 550 and 1600 kilocycles (Standard Broadcast Band) cause both the ionized *D and E layers* to produce skywaves. These same frequencies at night produce skywaves from the higher *F^2 layer*. This is why distant standard broadcast band stations which cannot be received in the daytime can be received at night.

In the daytime *ultra high frequency waves* between three and 30 megacycles produce skywaves from the high *F^1 layer*. To do this they pass through the *D and E layers*. These two lower layers of the ionosphere *partially block* ultra high frequency waves. At night these waves produce skywaves from the higher *F^2 layer*. Because at night there are no lower *D and E layers* to partially block the ultra high frequency waves, the skywave signal *will be stronger* than it is in the daytime.

Microwaves with frequencies *higher than 30 megacycles* pass through the ionosphere; therefore, they do not produce skywaves. For this reason, transmission of frequencies used by television and radar is limited to about 40 miles, and relay stations are used to extend their transmission range.

Select two pupils to draw two simplified diagrams of the ionosphere showing the differences between the structure of the ionosphere in the daytime and at night. Use the diagram in Fig. 41.2 as a model for the diagram of the ionosphere in the daytime. The diagram showing the ionosphere at night should have only one layer, the *F^2 layer*. It should be drawn at approximately the same heighth as the *F^1 layer* that is shown in Fig. 41.2. Use these two diagrams during the discussion of the pupils' reference reading to help them answer the next three questions. After the information has been presented, help the class summarize the facts. (See summary at the end of the chapter for the scientific findings for this inquiry.)

1. What is believed to be the source of the radiations that ionize the upper atmosphere? (The sun.)

2. Why would a change in the altitude of the ionosphere affect the distance that skywaves are transmitted? (Refer to the diagram of Fig. 41.1.) Discuss some of the experiences that indicate that the range (distance) of *vision* increases when landscapes are seen from greater heights, such as looking at a view from a second story window, a roof top, a hill top, the top of a very high mountain, and an airplane.

3. Why is it impossible to transmit waves that are used for television programs and radar as far as those that are used for broadcasting radio programs? (There are two reasons: (1) Wave frequencies that are higher than 30 megacycles do not bend around (are not diffracted by) objects. Frequencies below 30 megacycles do bend around objects. (2)

Waves that have frequencies below 30 megacycles produce skywaves in the ionosphere. Radio wave frequencies above 30 megacycles do not produce skywaves.)

3. Who are some of the scientists who have made important contributions in the development of electronic communications? What contributions did they make? Why have not all scientists who have made important discoveries and inventions during the past 25 years been given recognition for their individual contributions?

Develop the understanding that many scientists, over a period of approximately 150 years, have made important contributions in the development of radio, television, radar, maser, and laser. Ask the class to list as many scientists as they can whom they think should be given recognition for their contributions.

Select the names of the key scientists given in Table 41.1 to add to the pupil's list. Before making specific reading assignments, discuss several of the different classifications or titles that can be used to locate information about these scientists. Several clues regarding these classifications will enable the pupils to suggest additional ones. Contributions made by individual scientists are not always listed under their names in the index of a book. They are frequently classified under the specific contributions they made, such as vacuum tubes, cathode ray tubes, X-rays, television picture tubes, oscilloscopes, and the development of radar, maser, and laser.

Either assign to the pupils the names of scientists or ask for volunteers to obtain information about each scientist, his contribution, and the approximate date it was made. Also ask these pupils to summarize the important information in a brief written statement. After each report is given, have the summarizing statement read for the class to *evaluate*. Following the evaluation, if necessary, have the statement revised and written on a table similar to Table 41.1.

Help the pupils to develop the habit of looking for significant *relationships* in tables and charts and of making an *analysis of the relationships*. After giving the pupils time to study their completed table, guide the discussion of it with questions similar to the following ones.

1. **When does the table show the beginning of an acceleration in electronic developments? (About 1880.) Why? [(1) The existence of radio waves had been predicted. (2) The Crooke's tube, the father of the cathode ray tube, had been invented. (3) Improved methods for evacuating glass tubes had been developed. (4) The improvement of communications systems enabled scientists in the western hemisphere to exchange ideas more freely. (5) The expansion of industry developed the need for further improvements in communications systems.]**
2. **How much time elapsed between Maxwell's prediction of radio waves and the broadcasting of regular radio programs? (53 years; from 1867 to 1920.)**
3. **How much time elapsed between Hertz's discovery that Maxwell's radio waves existed and the broadcasting of regular radio programs? (About 34 years; from 1888 to 1920.)**
4. **How much time elapsed between the first transmission of a picture by radio waves until black and white television sets were common? (About 15 years; from 1922 to the middle of the 1930's.) In the 1930's television sets were being purchased by people living within a 40-mile radius of broadcasting stations. Approximately ten years later, relays were being built to serve communities that were too far away to receive broadcast directly from the broadcasting station's antenna.**
5. **When was radar first used in airplanes? (In 1937 it was used in a private plane. During World War II, radar was widely used by the armed forces.)**
6. **What electronic development probably prevented the Germans from overrunning Britain in World War II? (Radar.)**
7. **How much time elapsed between the early theory pertaining to the development of color television and its wide use by the public? (About 40 years; from 1928 to 1965.) State some of the reasons why this development was so slow. [(1) World War II delayed the development because the goverment contracted with the large manufacturers of electronic equipment to develop electronic equipment for the military. (2) The Federal Communications Commission required that transmitters must be able to broadcast color television programs that could be received in black and white as well as in color. (3) Color television sets were more than twice as expensive as**

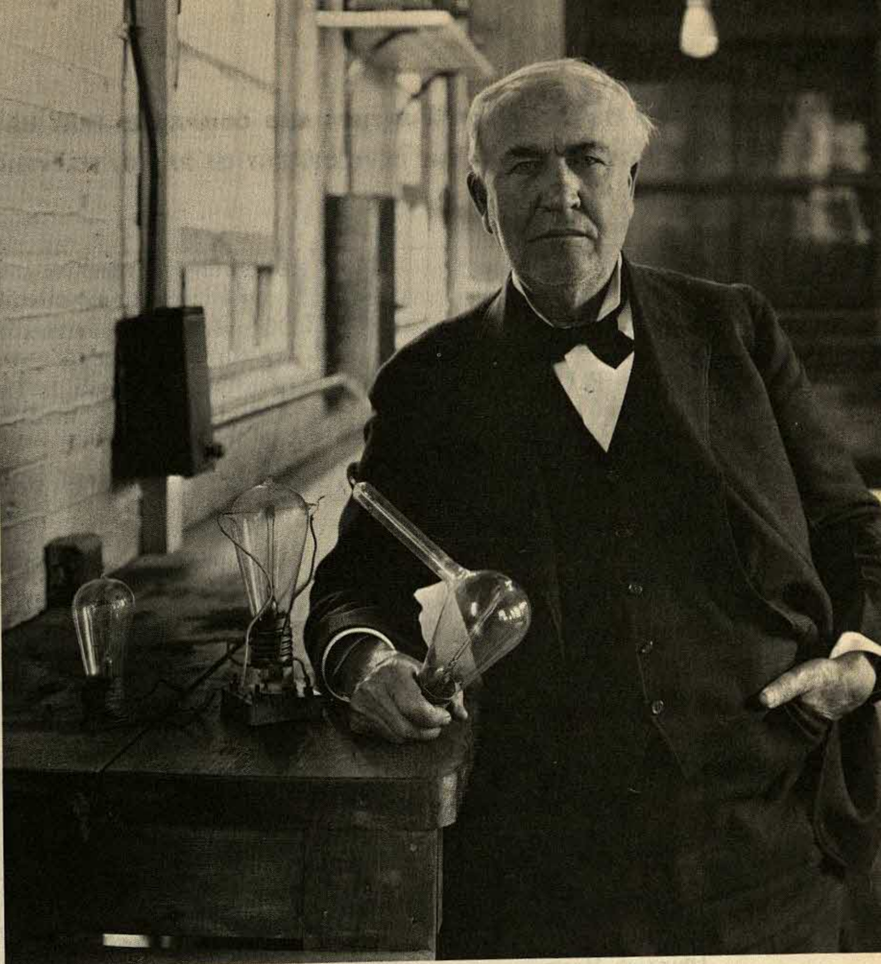


Fig. 41.3 Thomas A. Edison with his "Edison Effect" lamps (photo taken between 1917 and August 1919). The inventor's discovery of the "Edison Effect" in 1880 revealed the fundamental principle on which rests the modern art of electronics. *Courtesy U. S. Department of the Interior, National Park Service, Edison National Historic Site.*

black and white ones. (4) Only a very few programs were televised in color each day.]

8. Why are there so few important discoveries attributed to an individual scientist after 1946? (After World War II, both government and industry increased their support of pure scientific research. Such research has no foreseeable practical applications. Discoveries and inventions made in laboratories usually cannot be attributed to one person because teams of scientists work together on research problems.)

Encourage the development of a respect for *individual opinions* and a *sense of responsibility* for the promotion of continued growth in scientific discoveries, inventions, and developments. The pupils should be given time to think through the following problems and to express both the pros and cons on paper before they openly discuss them. State opinions regarding the trend toward governmental and industrial support of scientific research in both the pure sciences and the practical or applied sciences. What are some of the desirable and undesirable factors?

Check the points the pupils make, in order to substantiate their opinions, with these points for and against governmental and industrial support of research.

1. Pure research could be weakened if approval for conducting research is weighted by a sponsor's decision to finance most often research that will be useful to the sponsor. A scientist in pure research is not necessarily interested in the practical applications that may be made from his discoveries. He wants to be free to delve into the unknowns in his particular specialization.

2. Pure research scientists should not feel compelled to produce results within any specified time period. Governmental and industrial research laboratories must make yearly financial reports. Will they be able to justify a ten to 30 year program for financing research that may seem to be of no practical value?

Table 41.1

SOME OF THE MANY SCIENTISTS AND COMPANIES THAT HAVE MADE IMPORTANT CONTRIBUTIONS TO THE DEVELOPMENT OF RADIO, TELEVISION, RADAR, MASER, AND LASER

Name	Date	Contribution
Musschenbroek	1746	Discovered Leyden jar condensers or capacitors. Capacitors are used in electronic circuits.
Hans C. Oersted	1819	Discovered electromagnetism when he found that a wire carrying a current of electricity would deflect a magnetic needle.
Michael Faraday and Joseph Henry	1831	Both men, unknown to each other, discovered that an electromagnet could be made by winding a coil of wire around an iron core.
Samuel J. Morse	1842	Discovered that even though the telegraph cable that he was laying across a river was broken, he could receive telegraph messages.
Samuel J. Morse	1844	Developed telegraph from Faraday's and Henry's electromagnet.
Abbe Caselli	1862	Transmitted drawings by radio waves from Amiens, France to Paris, France. Radio waves were not discovered until 1886; they were referred to as electric waves.
James C. Maxwell	1867	Predicted mathematically that radio waves existed.
Thomas A. Edison	1873	Invented a television sending and receiving set, which worked with some success.
Williams Crookes	1880	Invented the cathode ray vacuum tube, which became known as the Crookes' Tube, and transmitted the first pictures with a cathode ray vacuum tube.
Thomas A. Edison	1883	Discovered that the heated filament in an electric light bulb emits electrical energy. This effect is known as the *Edison Effect.*
Paul Nipkow	1886	Patented the Nipkow Disc, which was later used to scan the scene being televised.
Heinrich Hertz	1886	Produced a laboratory radio transmitter and receiver, which provided evidence that Maxwell's theory on radio waves was correct.
Thomas A. Edison	1893	Discovered evidence that the Edison Effect was caused by a stream of negative electricity. See Fig. 41.3.
Guglielmo Marconi	1895	Made first demonstration of wireless (radio-telegraph).
Wilhelm Roentgen	1895	Discovered the existence of X-rays.
Ambrose Fleming	1897	Discovered that alternating current could be both rectified (changed to direct current) and amplified by a diode vacuum tube.
Guglielmo Marconi	1897	Demonstrated the feasibility of sending wireless messages to ships at sea.
Joseph J. Thomson	1897	Provided evidence of the existence of the electron. He also discovered that a magnet would deflect the beam of electrons in a cathode ray vacuum tube.
Guglielmo Marconi	1899	Invented the first tuned radio circuit and transmitted signals across the Atlantic Ocean.
Guglielmo Marconi	1900	Sent the first radio-telephone message.
Reginald Fessenden	1900	Transmitted speech for one mile by wireless (radio-telephone).
Guglielmo Marconi	1901	Sent the first wireless signal across the Atlantic Ocean.
A. R. B. Wehnelt	1904	First person to coat a cathode ray tube with a phosphor.
Ambrose Fleming	1904	Made first electron detector tube, called a *valve,* containing a filament and a plate.
Reginald Fessenden	1906	First broadcaster; by radio-telephone broadcast, he sent both a *message and music* on Christmas Eve, 1906.

Lee deForest	1906–7	Modified Fleming's valve, the diode, into an audion vacuum tube called a triode. Audions can be used to rectify current and to amplify voltage.
Lee deForest	1910	Broadcast an opera sung by Caruso from the Metropolitan Opera House.
Edwin H. Armstrong	1913	Used audion vacuum tube to generate continuous radio waves. He also invented the superheterodyne (superhet) receivers. Superhet radio and television receivers contain from two to five superhets that reduce the frequency of the radio carrier waves to intermediate frequencies. Superhets, or intermediate frequency transformers, are shielded by metal cans to prevent stray electromagnetic fields from entering the receiver. If these stray electromagnetic fields were not eliminated, distracting "hums" would be heard in the loudspeakers.
Reginald Fessenden	1920	Prior to 1913, he discovered the principle of the superhet that was adapted by Armstrong. Fessenden has more than 500 electronic inventions to his credit. He is also known for his promotion of radio for the public. In 1920, he began regular broadcasting of radio programs.
Arthur Korn	1922	Sent picture across the Atlantic Ocean by radio.
Charles F. Jenkins	1923	Developed one of the first television transmitters and receivers. He transmitted pictures of President Harding over a distance of 130 miles.
Vladimir Zworykin		Invented the camera tube called the iconoscope. It is still used for televising motion picture films.
H. Busch	1926	Discovered that magnetic and electric fields can be focused. Two fields surround the wires in a circuit in which electricity is flowing—a magnetic field and an electric field.
John Baird	1928	Used the Nipkow Disc to demonstrate that color could be transmitted by radio waves.
Bell Laboratories	1929	Demonstrated color television could be transmitted by wire from one room in a building to another room in the same building.
British Research Team working with Robert Watson-Hall	1930	Developed a radar system, which was later used (1938) to protect England's southeastern coastline.
Edwin H. Armstrong	1935	Demonstrated high fidelity reproduction of sound could be achieved by frequency modulation (FM).
Irving Wolff	1937	Used radar in his private plane.
Philo T. Farnsworth	1939–40	Demonstrated a television transmitter and a receiver. His camera tube, called an image dissector, produced better pictures than the iconoscope camera tube. RCA bought many of Farnsworth's television patent rights.
Alfred N. Goldsmith	1944	An RCA scientist who applied for a patent on a compatible color tube; in 1947, also applied for a patent on an improved color tube.
Ernest O. Lawrence	1946	Invented the Chromatron. The Chromatron is one kind of color television tube. He also invented the first television receivers for the consumer market.
RCA Scientists		Developed the Image Orthicon camera tube. This camera tube is today's standard television camera.
Bell Laboratories' Scientists	1943	John Bardeen, Walter H. Brattin, and William Shockley developed the transistor.
RCA	1950	FCC approved the tricolor compatible color television system developed by RCA.
Charles H. Townes	1954	Built and demonstrated the first maser.
Charles H. Townes	1958	Extended maser principles to laser.

This support is essential if pure research is to be carried on in any depth and breadth.

3. **Scientists must have a steady source of personal income. Prior to the twentieth century, scientists were frequently financed by such patrons and patronesses as kings, queens, and wealthy people who were interested in the promotion of new discoveries and inventions.**
4. **The highly specialized equipment and facilities scientists must have in this century are too costly to be financed by patrons. This support must come from government research foundations and large corporations with annual incomes that are large enough to support both pure and applied science research.**

After the pupils have presented their opinions, invite one or more adults who are trained in science to talk to them on this subject. If possible, obtain the opinions of people who are in pure and applied science research.

Help the class evaluate the opinions that have been expressed by the members of the class and by the science specialists. After the evaluation period, ask each pupil to write a second statement stating his opinions and whether they have been changed by the discussions.

4. What advances have been made in communications in the last decade? What are some of the advances predicted for the next decade?

Miniaturization of circuits and electronic devices and different types of *relay systems* are making it possible to communicate with all parts of the world and with objects in space.

Utilize the pupils' experiences and knowledge of modern communication media as well as information they can obtain from reading current literature to help them explore this inquiry. Their reading and discussion should develop some of the following ideas.

Miniaturization

Very small, solid state, semiconductors have largely replaced vacuum tubes, where size and weight are critical factors in communications systems.

The term *solid state* became widely used in the middle of the 1960's. Actually the public used solid state components nearly four decades earlier. The crystal detector used in radio crystal sets of the 1920's was a solid state device. The crystals in these sets were composed of a metal called galena. The *natural impurities* in the galena crystal made it possible to use this crystal for the same purpose as today's diode tube and solid state diode.

At the present time, semiconductors are *man-made*. The technical ability to make semiconductors is one of the exciting and important advances that has been made in learning how to control the movement of electrical particles.

Semiconductors are solid state devices that are made by distributing a known number of atoms of one element (impurities) into a crystal of another element.

See Chap. 38, Inquiry 2 for information about the man-made germanium crystals used in transistors and diodes. The early laser depended on a man-made ruby crystal containing a known number of chromium atoms (impurities). See Chap. 40, Inquiry 2 for information about the present and future uses of laser.

Transistors and diodes (solid state, semiconductors) have miniaturized electronic circuits. Compare the size and weight of transistor and vacuum tube radios. Pupils can also collect newspaper and magazine advertisements featuring the term solid state. How small are the smallest available radio and television sets? How have radio and television prices changed in the past decade?

Take a field trip to a telephone exchange to observe the miniaturized and automated circuits of telephone systems. Secure from the telephone company a list of the foreign countries to which phone calls can be made. Ask for a list of foreign rates. Inquire whether long distance rates and rates for phone calls to foreign countries have been increased or decreased in the past decade. Have the pupils write to the Bell Telephone Laboratories for information about their plans for future improvements. Are there plans for making direct dialing possible to any place on the earth? Are there plans for personal telephones to be worn like wrist watches? What future plans have they for a combination television-telephone?

Introduce the concept of printed circuits. Many automobiles have printed circuits in the back of the instrument panel. An automobile repair shop should be able to supply an old one, which the pupils can examine. Look for television advertisements that feature printed circuits. Discuss how printed circuits contribute to miniaturization and lower costs.

Super miniaturization has made it possible to combine solid state components (devices) and a printed circuit in a package called a *chip*. The whole circuit plus its electronic components is smaller than the period on a printed page. Ask the pupils to locate in current periodicals articles about chips. Ask an electronics supply store if they can supply a chip for the pupils to see. Discuss what chips are doing for future electronic communications.

Relay systems

Either natural or man-made relay systems are necessary to extend the transmission range of electromagnetic wave signals on a global and spatial scale.

Much progress has been accomplished toward global communication by the use of transoceanic cables, coaxial cables, radio telephone, relay booster towers, and also with satellites. However, rapid, 24-hour, daily communication service *to all parts* of the earth has not yet been achieved. Several types of electronic relay communication systems that do hold promise for 24-hour worldwide service have been tested.

One system uses transoceanic cables and radio telephones. In many countries, worldwide telephone service is limited to a few hours a day and the cost is too high for most people. Before this kind of communication system can be used on a wider scale, more transoceanic cables must be laid, and more radio telephone channnels must be developed. However, to complete and maintain such a system would be not only very costly, but also impractical, because it could not be used to carry television programs. The ultra high frequencies of television cannot be transmitted well either by telephone or telegraph cables.

A global network of relay stations for transmitting *television* and radar signals as well as telephone and radio signals, could be built on the land surface of the earth. This system would not interlock continents separated by large bodies of water, unless floating relay stations were also maintained on the oceans between these continents.

Another relay system uses *natural* atmospheric refraction to bend ultra high frequency electromagnetic waves earthward. It has been discovered that both the lower atmosphere (troposphere) and the ionosphere can be used to increase the transmission range of television. If different frequencies of carrier waves are transmitted skyward at an angle of 45 degrees, *blobs* of low density air act like glass lenses and bend the waves earthward. In the Arctic, television programs have been transmitted by lower atmospheric refraction, called *scattering*, for distances of 400 miles. Distances as great as 1200 miles have been achieved by *ionospheric scattering* of carrier waves between the frequencies of 30 and 50 megacycles.

Fewer ground relay stations would be needed if *ionspheric scattering* could be used. However, it is doubtful that this method for transmitting electromagnetic waves will be widely used for a global network, because it cannot be used effectively when massive electromagnetic storms are occurring on the sun. These storms affect wave transmission just as electrical storms on the earth affect radio and television reception.

Satellite relay systems may offer the best hope for global communications. More than one type of satellite has been tested. Echo I, the first communications satellite, was called a *passive reflector* because it had no relay equipment. This satellite *bounced*, or *reflected*, carrier waves as a mirror reflects light. Detecting electromagnetic waves from a passive reflector requires very powerful (high voltage) transmitters and extremely sensitive receivers. Both are expensive to build. For this and other reasons, it seems unlikely that passive reflectors will be used for global networks.

Telstar I, the second type of satellite tested, is called a *low altitude active repeater*. It was launched in an orbit that extended from 600 to 3500 miles from the earth. It weighed 100 pounds and was filled with very expensive electronic equipment. This equipment could receive, amplify, and retransmit carrier waves. For worldwide, 24-hour reception, at least 50 of these satellites will be needed. This is an excessively expensive project when you consider that the earth's drag (gravitational attraction) will pull these satellites earthward within a few years after they are launched. A global network of 50 satellites like Telstar also requires a great many

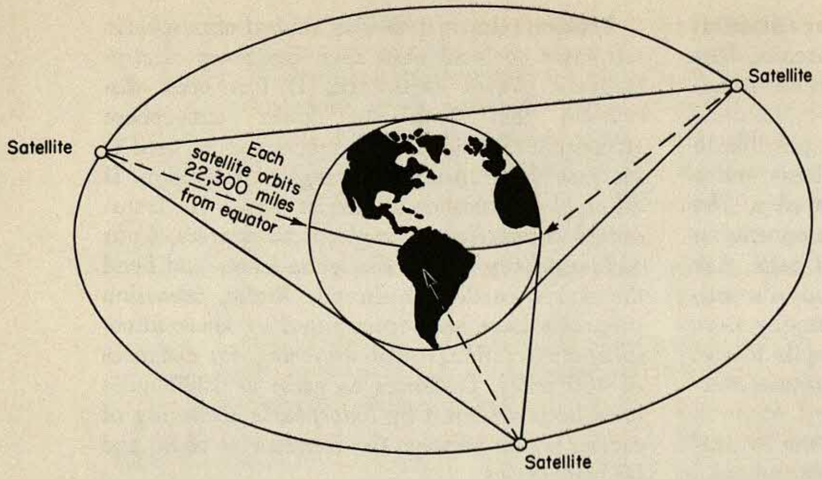


Fig. 41.4 Three relay satellites positioned in orbit to provide worldwide radio, telephone, and television communications.

tracking stations on the ground to detect the signals, amplify, and retransmit them to the receiving sets in the area.

A third type of communications satellite is called the *synchronous active repeater.* When three of these satellites are kept in an orbit at a distance of 22,300 miles from the earth's equator, they provide relay facilities for all of the inhabited parts of the world (see Fig. 41.4). To an observer on earth these three satellites will appear to be motionless because they orbit the earth in exactly the same time that it takes the earth to complete one rotation. Early Bird was the first high altitude, synchronous repeater satellite to be launched. At 22,300 miles from the earth's equator, the satellite is away from the earth far enough so that the earth's drag is reduced sufficiently to enable it to remain in orbit almost indefinitely. It is also high enough for it to provide trans-Atlantic communications between densely populated areas of the world.

When the technical problems were overcome more satellites like Early Bird were launched. (1) Technical ability was needed to launch these satellites with enough precision to place three of them at the exact distance from the earth's equator and exactly equidistant from each other. (2) Technical precision was needed to attain the same velocity for each satellite, so that each would remain in orbit always equidistant from each of the other satellites.

Because the need for telephone, radio, and television global networks was so great, a synchronous satellite system was developed during the late 1960's. On Christmas Eve 1968, more than a billion people around the world received, either on television or radio, a live broadcast by Apollo astronauts from the vicinity of the moon.

The establishment of global television networks makes it necessary either to adopt a universal language for broadcasting purposes or to have simultaneous translations into the thousand or more languages and dialects used in different parts of the world. It is also likely that a universal language will be adopted for global communications, because the meaning and intent of words are frequently lost when they are translated from one language or dialect into another one.

Worldwide television broadcasting could become a powerful educational tool if it were widely used. Imagine the changes that would occur if programs on public health, safety, improved methods of agriculture, and building construction were brought into the homes of a billion people.

Put a title, such as *Global Neighbors Communicate,* on a bulletin board, and ask the pupils to collect news items about new technical and electronic advances that are helping to make a global communications network an educational tool. On this bulletin board list some of the many current sources available for this kind of information. The information developed in this inquiry was obtained from current copies of such periodicals as *Current Events, Weekly Reader, Current Science and Mathematics, Science Newsletter, The Scientific American, Readers' Digest, National Geographic,* the science sections of *Time, Life, News Weekly,* and from daily newspapers.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. A system called telemetry makes it possible for stations on the earth to send information to spacecraft and to receive information from them. Spacecraft that are equipped with tape recorders are programmed to store information on magnetic tape and to transmit this information when a command (signal) is received from the ground station. Spacecraft equipped with a television transmitter can also store television pictures on magnetic video tape and transmit these pictures when a command signal is received from the ground station. Astronauts have used television to send pictures to earth.

2. A region in the upper atmosphere, called the ionosphere, *reflects* some frequencies of radio waves back to the earth. Some of the gases that compose the ionosphere are electrically charged (ionized). The ionosphere is frequently referred to as the Kennelley-Heaviside Layer. The ionosphere is named for the two scientists who discovered it.

There are several theories that state the reason for the existence of the ionosphere. At the present time, the most acceptable theory states that the ionosphere is charged by ultraviolet radiations emitted by the sun. The ionosphere is composed of one or more layers that reflect certain radio frequencies back to earth. The ionosphere does not reflect radio waves like a mirror reflects light. When radio waves strike the ionosphere, these waves produce secondary waves of the same frequency. The secondary waves produced in the ionosphere are transmitted to the earth. These secondary waves are called *skywaves.* Radio wave frequencies lower than 30 megacycles are transmitted by the ionosphere back to the earth as skywaves. Radio wave frequencies higher than 30 megacycles pass through the ionosphere.

In the daytime, the ionosphere is composed of three layers. At night, the two lower layers combine with the upper layer to form one layer. Radio waves that are transmitted from the upper layer of the ionosphere are weaker in the daytime than they are at night because they are partially blocked by the lower layers of the ionosphere. Radio programs that are transmitted by skywaves can be received from greater distances at night, because the ionosphere is farther from the earth at night.

3. Many scientists have made important scientific contributions to the development of electronic communications. There is usually a lag of ten or more years between the time an important scientific discovery with practical applications is made and the time these applications are developed. Since World War II, much of the financial support and the facilities needed to conduct pure and applied scientific research have been contributed by the government and industry. Both pure and applied scientific research are important to the advancement of knowledge and the improvement of living conditions.

4. The term *solid state* in electronics refers to devices that contain semiconductors to control the movement of electrons. Diodes and transistors are solid state devices. The use of solid state semiconductors has made it possible to miniaturize electronic devices.

Television and telephone communications are now possible *between* most of the inhabited parts of the world by using *high altitude synchronous active repeater satellites as* relay stations. International television communications should be used as a tool to improve the health and living conditions of all people.

Chapter Forty-Two

Plant Adaptations for Surviving Seasonal Changes

Observing a Garden at the End of the Growing Season

INQUIRIES

1. What can be learned by observing flowering plants in a garden?

2. What can be learned by growing seeds?

3. What happens to plants at the end of the growing season? What happens to plants when frost occurs?

1. What can be learned by observing flowering plants in a garden?

Arrange for the class to visit a garden when many annual plants are in bloom. Ask permission to visit the garden. Also ask the owner to be present to help the children make meaningful observations about the flowering plants. Explain to the gardener what you plan to have the children observe in the garden and how the observations will be recorded. At the same time ask him for help with identification and learn if he will be willing to give the class a few leaves and flowers.

Before going to the garden, have the children agree upon a list of things they should and should not do at the garden. Ahead of time make and mimeograph data cards, which the children will need for recording their observations. Take these cards, pencils, a pad of paper, and sandwich bags on the trip.

At the garden, have the children observe the different colored flowers. Write the colors the children name in a column on the pad of paper. In a second column, write the names of all the plants of each color, which the *children can identify*. Ask the gardener to identify the plants the children cannot name. Also write the unfamiliar names in the second column. Have the children repeat these new names and associate them with the correct flowers.

Next, observe the different sizes and shapes of the flowers. The shapes of flowers can be associated with bells, trumpets, stars, pincushions, and other shapes with which children are familiar. Read the names on the list one by one and have the children observe each flower and describe its shape. Add this information about each flower in a third column. Also have the children identify by name both the largest and the smallest flower in the garden. Write this information in the third column.

One by one, read each flower's name, color, and shape from the list. Ask a few children to locate the flower and to smell it. Ask them to describe the odor. Suggest that a flower may smell like perfume, spice, fruit. It may smell pleasant, unpleasant, or have no odor at all. In a fourth column, record the information they give about the odor of each flower.

Count the number of petals of such flowers as petunias, nasturtiums, phlox, morning glories, and so on. Observe that some flowers, such as asters, daisies, and chrysanthemums, have many petals. Record this information.

Observe the differences in the structure of the flowering plants. Some will have a single main stem; some, several main stems; and still others, many stems. There may be vines that climb or runners that trail on the ground. Have the children determine the type of stem structure for each flowering plant on the list. Have them also decide which flowering plants have hard, soft, smooth, rough, hairy, or thorny stems. Record this information.

Have the children observe the different sizes and shapes of leaves. Suggest that leaf shapes are described by such words or phrases as round, heart-shaped, palm-shaped (like the palm of the hand), shaped like blades of grass, feathers, triangles, and so on. Have the children describe the size and shape of each flowering plant's leaf for the record.

Now have the children locate and name some of the tallest and shortest plants in the garden. Young children who do not know the units of measure can use the hand for a gauge. (An aster may be five times as tall as one of their hands, a nasturtium may be less than two hands tall.) Record this information.

Find a place either in or near the garden where the class can sit down to summarize some of the things they have learned. At this time ask each child to select a plant about which he will compose a story when he returns to school. Pass out mimeographed cards on which there is an outline similar to the one at the end of this paragraph. Ask each child to write information about his chosen flowering plant in the blank spaces. Explain that these few facts about his chosen flower will help him to write the kind of story that will really describe his plant.

FLOWER FACTS

1. Flower
    - Name ______________________
    - Color ______________________
    - Size ______________________
    - Shape ______________________
    - Number of petals ______________
    - Odor ______________________
2. Plant
    - How tall ____________________
    - Number of stems ______________
    - Kind of stem _________________
3. Leaf
    - Size ______________________
    - Shape ______________________

Ask the gardener to give each child a leaf from the flowering plant he has selected to write about; and make each child responsible for getting his leaf sample back to school. Label and press these leaves as soon as the pupils return to the classroom. (The leaves can be dried by placing them between layers of newspapers, and pressed by placing books or heavy objects on top of them.)

Finally, ask the gardener if he can give the class mature seed pods from some of the plants in the garden. As the gardener collects these seed pods, place each kind, together with a label stating its name, in a separate sandwich bag. Plan several class periods for the children to discuss the trip, to write, illustrate, and to read their stories. Use at least one of these periods to examine the seed pods and the seeds that were collected and to make plans for growing the seeds during the next growing season in their region.

2. What can be learned by growing seeds?

Use a magnifying glass to examine the seeds that were collected from the flower garden. Observe the differences in their size, shape, color, and texture. Also, count the number of seeds contained in each different kind of seed pod.

Write the following five statements on a chart and record the number of positive and negative responses the pupils make to each. Emphasize that their answers to these statements will be checked and corrected after they have planted seeds and watched them grow.

STATEMENTS	YES	NO
1. All seeds planted will grow. (This is not likely.)	____	____
2. Some seeds planted will grow. (This is likely.)	____	____
3. The tiny plants (seedlings) will look like the parent plant. [The seed leaves (first leaves) will not look like the parent plant. The true leaves (second leaves) will look like the parent plant, but at first, they will be smaller and a lighter shade of green.]	____	____
4. Some kinds of seeds begin to grow sooner than others. (Even if only a few kinds of seeds are planted, the results should show that there is a difference in the length of the germinating period for different kind of seeds.)	____	____
5. If the plants continue to grow, they will produce blossoms *before the end of one growing season.* (This depends upon whether the plant is an annual, a biennial, or a perennial. See Table 43.3. It also depends upon the length of the growing season.)	____	____

Put the seeds from each different kind of flowering plant in labeled bags. Seal and store in a cool dry place until planting time.

When the time arrives for planting seeds, obtain the materials needed to germinate them. Seeds germinate well in a mixture of one-third clean sand, one-third top soil, and one-third of either perlite or peat moss. (Perlite is a loose granular product often used by florists. When they deliver cut flowers in vases of water, they use either perlite or vermiculite in the vase to hold the flower arrangement in place.) Mix the three ingredients thoroughly and moisten the mixture. Test a sample of this potting medium to find cut whether it has enough water for seed germination. (Take a sample of the mixture in one hand and squeeze it. If a few drops of water are released when the mixture is squeezed, it contains the correct amount of moisture.)

Use a separate aluminum foil baking dish for each kind of seed. To provide adequate drainage, cover the bottom of each of the aluminum dishes with either a layer of gravel or small broken pieces of clay flower pots. Fill each of the pans to one-half inch of the top with the potting mixture.

Count the number of seeds that are to be planted in each container. If necessary use a magnifying glass. Discuss the importance of planting seeds at the correct depth. (Seeds that are planted too deeply may not develop into plants.) Most seeds should be planted at a depth that is approximately twice the height of the seed. Many flower seeds are so small that it is difficult to determine the distance from the bottom of the seed to the place where the young plant will emerge. (In such cases, either the height or the length can be used.) Estimate the depth at which each of the different kinds of seeds should be planted. (Very tiny seeds may be scattered on the surface of the soil and covered by sprinkling dry top soil over them.)

Increase the children's choice of seeds to plant, by adding some common vegetable seeds to the collection of flower seeds. Boys often prefer to germinate vegetable seeds. Plant the seeds and place each of the foil containers in a transparent plastic bag. Use a wax marking pencil to write on the bag the name of the plant, the number of seeds that are planted, and the date they are planted. Seal the bags. Place the germinating pans in a part of the room where they will be in subdued light.

Check the pans daily for the following conditions.

1. *The appearance of water on the inside of the plastic bag.* Have the children guess why the plastic bags are used. (They are used to prevent the water in the germinating mixture from escaping into the room.)
2. *The appearance of mold.* (If mold appears, remove the plastic bag for at least 24 hours and then replace it.)
3. *Germination.* On the plastic bags, record the dates the seedlings appear.
4. *After germination occurs.* Use a pin to make several dozen perforations in the plastic. (The perforations will make it possible for the air in the room to move in and out of the bag. This circulation of air through the plastic will help to equalize the temperature of the air above the germinating pans with the air temperature in the room.)
5. *Number of seeds that germinated.* After the seeds have germinated, compare the number of seeds planted with the number of seedlings. Record this number on the plastic bag.
6. *When the true leaves (second leaves) appear,* remove the plastic bag and place the containers where they will receive several hours of sunlight daily. (The plastic bag is removed to prevent the tender leaves of the seedlings from being damaged by rubbing against the plastic.)

Some children will be interested in experimenting to discover whether seeds will germinate when they are planted too deeply. Have these children plant the seeds of such plants as asters, petunias, poppies, and snap dragons at depths of three to four inches in the same kind of potting mixture. Be sure to use a layer of gravel under the potting mixture. Clay flower pots can be used for this experiment. Use *two* flower pots for each kind of seed that is to be planted. One pot of each pair is for a control. In all the *control pots, plant the seeds at the correct depth.* After the seeds are planted in all the pots, place them in separate clear plastic bags. Tightly tie the tops of the bags. When the seeds in the control pots germinate, record this date. Wait several more days or until the children are certain that the seeds, which were planted too deeply, have had time to germinate. Did none, some, or most of the seeds that were planted too deeply germinate? (Some of the seeds may germinate, but the germination period will be longer and the seedlings will be weaker than those in the control pots.) Empty the contents of the pots in which seeds were planted too deeply. Examine the potting mixture with a magnifying glass for evidence of seedlings that may have germinated and then died before they could push their way up through the soil.

Experiments similar to the following series will help the pupils discover why gravel and the different substances in the potting mixture were used.

1. Obtain four identical flower pots. Follow the directions given previously for mixing the potting medium. Prepare enough of this mixture to fill all four pots. Place a *measured amount of gravel* (about one inch) *in two* of the pots. *Do not put any gravel in the other two pots.* Place the same amount of the potting mixture in all four pots. Pack the mixture firmly. Set the pots in separate containers. These containers will catch the drainage water from the pots. Use a teaspoon to measure the water used in this experiment. Slowly dribble one teaspoonful of water after another *into one of the two pots that contains both gravel* and potting mixture. Do this until drainage water appears in the container under this pot. Dribble *the same number* of teaspoonfuls into each of the other three pots. Through which pots does the water drain more rapidly? (Through the two pots that contain both the gravel and the potting mixture.) Through which pots does more water drain? (Through the two pots that contain both gravel and the potting mixture.)

As soon as the water stops draining through the holes in the bottoms of the four pots, repeat the experiment and observe the results. (Each time the water will drain more rapidly through the two pots that contain both gravel and potting mixture, but a new factor will be observed. As the contents of the pots become more nearly saturated with water, the rate of drainage will be slower. If the experiment is repeated several times, the water will finally remain on the top of the potting soil for several minutes.) Should any children ask why water remains on top of the soil for longer periods of time, discuss the explanation given on page 494.

Ask the pupils to guess why gravel is placed in the bottoms of containers in which seeds and plants are grown. (Gravel provides the drainage that is necessary for plants when they are grown in containers. When the soil in which plants are growing receives too much water, the gravel drains away the excess water. Both sand and gravel also provide the drainage needed for plants that grow outdoors in the ground.)

Some of the pupils may want to find out what happens when the soil, in which plants grow, receives too much water. Encourage these pupils to think of different experiments they can do to make this discovery. The following is one experiment that can be done. Place one seedling in each of the four pots used in the previous experiment. Set the four pots in one large container. These four pots will not be watered from the top. Instead, they will receive water from the container. Maintain the water level in the container at a height that will keep the top of the potting mixture in the *two pots* that contain *both the gravel and potting soil moist but not wet.* Observe what happens to the seedlings in the four pots at the end of one day, three days, five days, and from six to ten days. (For the first few days, no changes may occur. In six to ten days, the leaves of the seedlings, in the pots that are receiving too much water (the pots that do not contain gravel), will turn yellow and will eventually fall from the plants. A few days later, the stems and roots of these seedlings will die.) Emphasize the fact that the plants in the pots that contained gravel did not die. Why? (The gravel drained the excess water from the soil.)

2. Experiment with gravel, sand, perlite or vermiculite, peat moss, and top soil. Discover which materials are used for drainage and which ones are used for absorbing water. Encourage the children to devise their own experiments.

Here is one experiment that can be done. Obtain six small identical flower pots and six clear glass containers (use them to hold the pots). Measure equal amounts of each of the following substances: (1) gravel, (2) sand, (3) perlite, (4) peat moss, (5) top soil, and (6) top soil over gravel. (Since the gravel in number 6 is to be placed in the bottom of one of the pots, do not mix the gravel and the top soil together. Use enough gravel to completely cover the bottom of pot number 6.) *Pack* each of the six substances firmly into separate pots. Allow enough space at the top of each pot for the water that is to be added. Set each pot in a glass container.

Use a teaspoon for measuring and dribbling the water into each of the six pots. Slowly dribble one teaspoonful after another into the pot that contains both gravel and top soil (pot number 6). Continue to add teaspoonfuls of water until it begins to flow through the drainage hole into the glass container. Note the number of teaspoonfuls of water that was added to pot number 6, then slowly dribble this same amount into each of the other five pots. Observe what happens to the water. Through which one of the pots does the water drain the fastest? (The pot containing the gravel.) Through which one does the water drain most slowly? (The pot that contained the peat moss.) In which pot does the water remain on top of the substance for the longest period of time? (The pot containing the peat moss.)

Write the names of the substances on the chalkboard according to the length of time (rate) it took the water to flow through the six pots. [The rate of flow from fastest to slowest is (1) the pot containing gravel, (2) the pot filled with perlite and the pot of sand, (3) the pot of top soil over gravel and the pot of top soil, and (4) the pot of peat moss.]

Find out whether there has been any change in the level of the substances in each of the six pots. (The level of the gravel will be approximately the same; there may have been slight settling caused by the water as it flowed through There are two reasons why the level of the sand will have changed: (1) Sand becomes more closely packed when it is wet. (2) Some of the fine grains of soil wash through the drainage holes in the pots. The level of the peat moss will also have changed because it expands as it absorbs water.

Lift each pot above its container and observe whether any water is trickling through. When the water has stopped dripping through the drainage holes in the pots, use the teaspoon to measure the amount of water that drained into the containers. Through which substance did the most water drain? (The gravel.) Through which did the least water drain? (The peat moss.)

Repeat the previous experiment several times and note the differences in the results. (Each time the experiment is repeated, the water will stand for a longer period of time on the tops of all the pots, except the one containing gravel.) Find out whether the pupils can explain why this happens? (When the substances are dry, the spaces between the particles contain air. When the substances are wet, water replaces the air and, as more and more water is added, the spaces become smaller. There are two reasons why these spaces decrease in size: (1) The particles become packed more closely together (as in sand and top soil). (2) The particles expand when they absorb water and therefore occupy more space (as in perlite and peat moss).

Place the six pots in a container to dry. When the sand in pot number two feels dry, pour the contents of each of the six pots onto separate, folded paper towels. Press each of the substances against the towel. How many substances leave wet spots on the paper? (Three.) Name these substances? (Perlite, peat moss, and the top soil from the pot that had no gravel in the bottom.) Have several of the children squeeze each of these three substances between their fingers to find out if they feel wet. (They do.)

Help the pupils classify the five substances used in the experiment into two categories: (1) *substances used for drainage* (gravel and sand), and (2) *substances used to absorb water* (perlite, peat moss, and top soil).

Summarize the results of the seed germinating experiences and check these results with the children's predictions for the first four statements listed at the beginning of this inquiry.

Water the plants that are growing in each of the germinating pans and remove at least one seedling from each. Note whether the roots and root hairs on the different kinds of plants are the same length, width, shape, and color. (They will not be.) Use a magnifying glass to examine the roots, root hairs, stalks, and leaves of these seedlings.

Select several of the healthiest seedlings from each of the germinating pans and transplant each into a small pot. Discuss why seedlings need to be planted in separate pots. There are several reasons: (1) The roots need more room to spread, both outward and downward. (2) More soil is necessary to produce a strong plant. The roots of plants absorb soluble minerals from the soil. These are necessary for growth. (See Chap. 12.) (3) The leaves of plants must be exposed to sunlight if they are to produce food. Leaves that are crowded too closely together cannot get the sunlight they need for growth and food-making.

Put a layer of gravel in each pot and cover with potting soil. Use a teaspoon for removing the selected seedlings from the germinating pans. Try to push the spoon downward into the soil at least one inch away from the stem of the plant in order to remove the growing roots in a ball of soil. Make a hole in the potting soil, which is large enough to hold the ball of roots and soil, without disturbing the soil clinging to the roots. Hold the plant at the proper position in the pot so that it will be *replanted at the same depth* at which it was growing in the germinating pan. Press the potting soil firmly around the stem of the plant. Always repeat these procedures when transplanting.

Place these transplanted seedlings in subdued light for approximately one week to allow time for the plant to recover from the shock of being moved and to permit the roots to become established in the soil. Make daily checks to discover whether the soil in the pots feels moist. If it does not, add a *small* quantity of water.

Use the remainder of the plants in the germinating pans for a control. Let them continue to grow in the germinating pans. Find out what happens *when plants are overcrowded.* Place both the crowded seedlings in the germinating pans and the transplanted seedlings in the same subdued light, and water all of them whenever the soil feels dry.

Approximately 7 to 10 days after the transplanting has been done, place all of the seedlings in a location where they will receive several hours of sunlight daily. When *differences in the color and size of the stems and leaves* can be readily observed, compare the transplanted plants with the control plants. (The transplanted plants should have thicker stems, and leaves that are larger and a darken shade of green.)

Make frequent checks on the plants in the flower pots to see if they need to be transplanted again. (If the roots extend through the hole in the bottom of the pot, the plant should be repotted.) When any plant needs to be repotted, move it into a larger size pot. Use the same procedures that were used previously to prepare the drainage and potting soil. Water the soil thoroughly before attempting to remove the plant from the smaller pot. To loosen the soil from the sides of the pot, turn the pot on its side and gently tap the sides and bottom with a garden trowel or a large mixing spoon. Then tip the pot until the soil and the plant slide out of the pot in one piece (see Fig. 42.1). The remainder of the procedure for transplanting is the same as it was for transplanting the seedlings from the germinating pans into the small pots.

If the plants are large enough and if it is the right season to grow them outdoors, ask a child to take the plants home and plant them in his

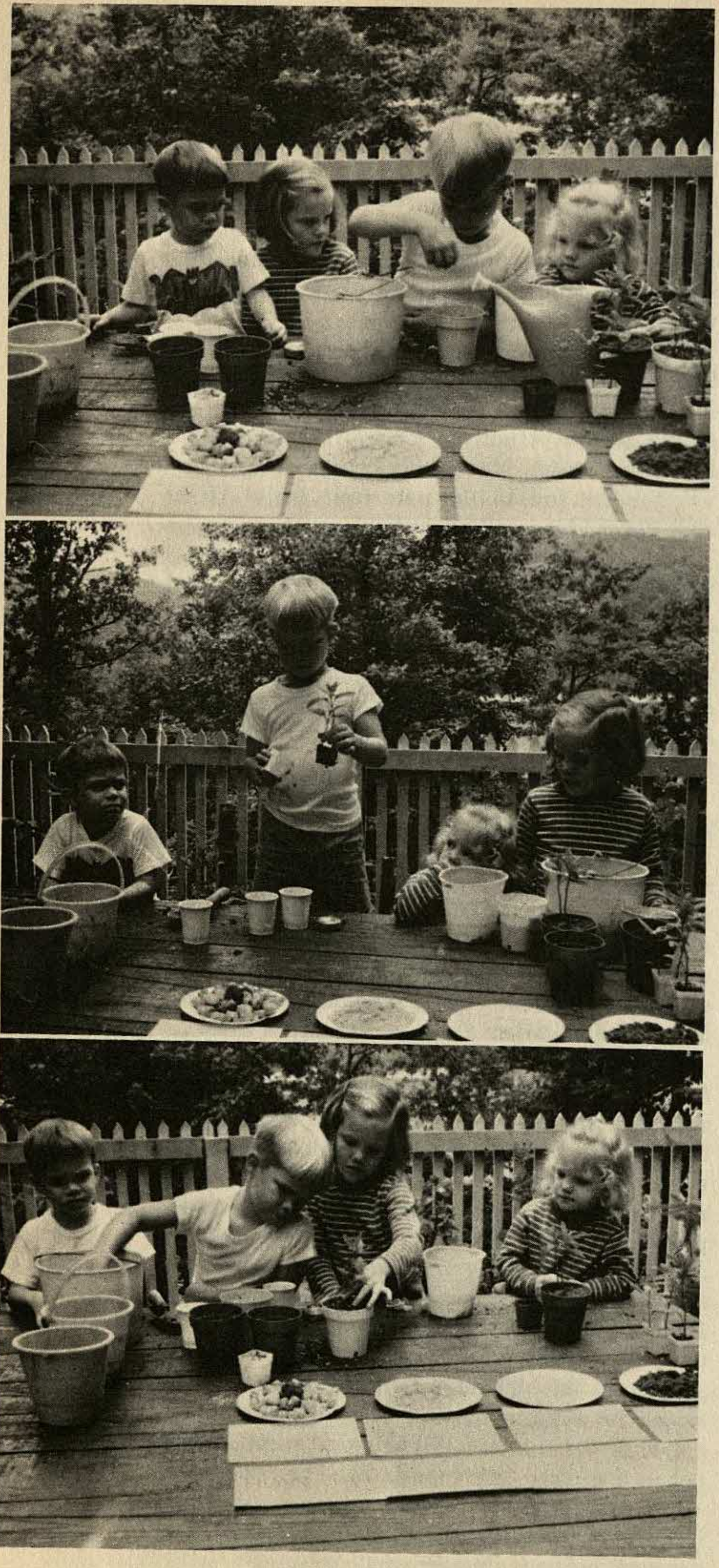


Fig. 42.1 Children transplanting plants from small pots into larger pots.

garden. Make the necessary arrangements for the class to visit these plants at the end of the growing season to find out whether they have continued to grow and have produced flowers.

3. What happens to plants at the end of the growing season? What happens to plants when frost occurs?

At the end of the growing season, visit the garden where the seedlings, which the children grew in Inquiry 2, were transplanted. Observe what has happened to the seedlings. (They should have grown and produced blossoms and seeds. If the seeds of these annuals are ripe the plants will also be dying.)

Pull up one or more of these dead plants. Find out if the children know why these plants are called *annuals*. (An annual lives for only one growing season. It grows from seed, blossoms, produces seeds, and dies in the same growing season.)

If the garden is in an area where frosts occur, discuss what a severe frost may do to plant leaves, stems, and roots. Examine many plants in the garden before a frost. Make a list of the plants the children can identify by name. Ask them to guess which parts of each plant may be killed by frost. Record their predictions.

After the first hard frost, return to the garden to discover which of their predictions seem to be true. Ask the gardener's permission to examine the stems and leaves of the plants that appear to be frosted. (The first day after a hard frost, the leaves of many different kinds of plants will be wilted and will feel soft to the touch. Also their color will have changed to either a dark brown or black. Several days after the frost, these leaves will become brittle and they may crumble when they are touched. They are also likely to fall from the plant with the slightest jar.) Cut the stems of several different plants that appear to be dead. Examine the cut end. Slit the stems lengthwise and examine them again. Cut several stems that appear to be alive. Also cut these stems lengthwise and compare them with the first stems. [The inside of stems that are alive will either be green or they will have a green tissue just beneath the skin (bark) of the plant. The inside of dead stems will vary in color from a pale yellow to a dark brown. The green coloring in live stems is chlorophyll. It will have disappeared (decomposed) if the stem is dead.]

Develop the concept that some kinds of plants are less sensitive to frost than others. (Such plants as petunias, asters, calendulas, and chrysanthemums may survive through several hard frosts. These plants are called *hardy or frost resistant.*) Identify some of the hardy plants in the garden whose leaves, stems, and flowers have not been damaged by early frosts.

When the gardener has removed dead plants and dead foilage from the garden, take another trip to the garden. (Where no frost has occurred in subtropical or tropical gardens, this trip may be made at the end of the growing season for annuals. Winter frosts sometimes do occur in the subtropics. If you live in a subtropical area where this happens, visit the garden after a frost.) On this trip help the children observe:

1. Which plants have been removed from the soil and destroyed? (All of the annuals.)
2. Which plants have been cut back to the ground? (All of the biennial and perennial herbs, with the possible exception of the chrysanthemums. In localities that have cold winters, chrysanthemums may bloom as late as the Christmas holidays.)
3. Which plants have stems remaining above the soil? (All shrubs and trees.)

After making these observations, help the pupils to classify the plants into three categories: (1) *plants that completely die at the end of one growing season;* (2) *plants that die back to the ground at the end of the growing season;* (3) *plants that do not die back to the ground at the end of the growing season.*

At the beginning of the next growing season for your area, make a final trip to the same garden and have the children take with them the plant list that was made in the previous inquiry. Ask the gardener what kinds of seed he has already planted or intends to plant. Find out from him whether any of the annuals in his garden ever came up from seeds that remained in the ground during the dormant season. (Frequently, even in areas where there is either a very cold or very dry dormant season, petunias, asters, violas, and annual poppies do come up from seed year after year. In milder climates, many seeds of additional annuals survive in the ground through the dormant season.)

Take a final walk through the garden and look for the new stems and leaves on those plants that died back to the ground at the beginning of the dormant season. Emphasize the fact that these new stems and leaves are developing from *the parts of the plant* that remained alive under the soil through the dormant season. (Avoid calling the parts below the ground root stalks, bulbs, or tubers, unless the pupils are familiar with these terms.) Also observe whether leaf and flower buds are beginning to appear on the stems of plants that were not cut to the ground at the end of the growing season.

See the chapter summary of process skills on the back endpaper of this book for process skills that can be practiced while developing the inquiries in this chapter.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. The blossoms of flowering plants differ in color, shape, and odor. Different kinds of flowers have petals that vary in number, size, and shape.

Some flowering plants develop one main stem, others a few main stems, and still others many stems. Some plant stems develop into vines or runners. Stem textures vary. They may be soft, hard, smooth, rough, hairy, or thorny.

The leaves of flowering plants vary in size and shape. Flowering plants vary in height. Flowers produce seeds if they have been fertilized.

The seeds of different kinds of plants vary in color, shape, size, and texture.

2. Seeds will not develop into plants if they are planted too deeply. Plants need space to develop strong roots, stems, leaves, and blossoms. Some kinds of seeds germinate more rapidly than others.

Plants that are grown indoors need to be planted in pots containing substances that control the amount of water that remains in the pot. Gravel and broken pieces of clay flower pots are often placed in the bottom of pots to provide for drainage of excess water.

A good potting mixture consists of equal parts of sand, top soil, and either peat moss or perlite.

3. Frost kills the leaves, stems, and roots of many plants. These plants are called annuals, because they die at the end of the growing season. They will die even where frosts do not occur.

Other plants whose leaves and stems die at the end of the growing season have parts under the ground that survive the dormant season.

Only the leaves of certain kinds of plants die at the end of the growing season.

Chapter Forty-Three

How Annuals, Biennials, and Perennials Survive a Dormant Season

INQUIRIES

1. How do annual plants survive dormant seasons?

2. How do biennial plants differ from annual plants? How are the underground parts of biennials classified? What adaptations do biennials have that enable them to survive a dormant season?

3. Why are some kinds of plants called perennials? How do perennials differ from biennials? How are the underground parts of perennials classified? What adaptations do perennial plants have that enable them to survive dormant seasons?

1. How do annual plants survive dormant seasons?

Collect a variety of *large, mature,* dry seeds from annual plants. Bean, mellon, corn, pumpkin, squash, watermelon, and sunflower seeds, as well as cereal grains are large enough for pupils to observe their adaptations for survival.

Observe and experiment with seeds to discover some of the reasons why they can survive. [This inquiry develops three reasons: (1) There is a miniature plant called *an embryo* inside the seed. (2) Inside the seed, there is food on which the developing embryo can live and grow until the plant is large enough to manufacture its own food. (3) The embryo and the food are protected by a seed coat or a membrane.]

Have the pupils feel the seed coats of different kinds of seeds. Some will feel as smooth as they would if they had been waxed or varnished. Others will feel like leather. Examine the seed coats with a magnifying glass. Soak the seeds overnight in water. Remove the seed coats and reexamine them with a magnifying glass. The membranes of seeds that split into halves (black eye peas, lima beans) are easily removed. Press the edge of the thumbnail along the ridge of the seed. This ridge is opposite the "eye" (hilum) of the seed. The "eye" is the place where the seed was attached to the seed pod. Carefully pry the two halves of the seed apart. Observe that the pointed end of the embryo (hypocotyl) is embedded in a "pocketlike" membrane located back of the "eye." The entire seed will split into halves and the embryo with its two tiny leaves (plumule) and the pointed end (hypocotyl) will be visible (see Fig. 43.1). The embryo is attached to the two parts of the seed. Have the pupils decide the value of these two parts. (Each cotyledon contains food for use of the young plant until it produces its own food.) After the seeds have been opened, the membranes can be removed from the two parts of the seed.

The outer membrane of a sunflower seed can be opened by gently pressing the two flat sides of the seed together. This pressure causes the pointed end of the seed to pop open. Start with this open pointed end and press the edge of the thumbnail along one side of the seed. Pry the two parts of the seed coat apart. Observe that a membrane surrounds the stored food and that only the tip of the embryo can be seen projecting from the pointed end of the stored food. Also observe that the inside of the seed does not split into halves like the pea and bean seeds did. Why? (The membrane surrounding the stored food must be broken before the seed meat will split apart. When this membrane is cut with the thumbnail, the seed meat will split into two parts.)

The seed coat of corn is very difficult to remove. A sharp tool, such as a paring knife or a single edged razor blade, is needed for this job. Lay the seed on a cutting board and carefully slice off the broad end of the seed. Carefully whittle away the yellow part of the seed. The embryo is located in the middle of the stored food and it extends to the pointed end of the kernel. The egg-shaped embryo is encased in a thick translucent membrane. A few corn seeds can be opened by an adult to allow pupils to see the embryo.

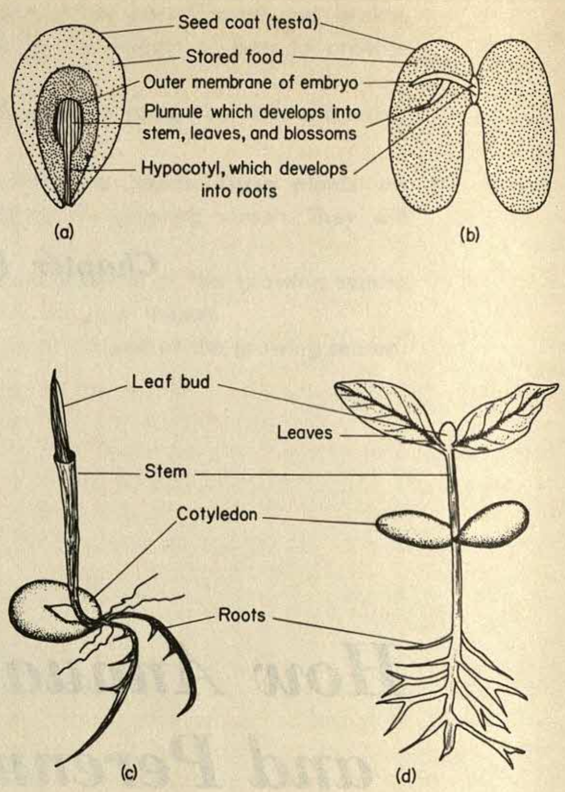


Fig. 43.1 The physical composition of the seeds and seedlings of monocotyledonous and dicotyledonous plants. (a) A monocotyledon, the corn seed; (b) a dicotyledon, the bean seed; (c) seedling of a monocotyledonous plant, corn; (d) seedling of a dicotyledonous plant, bean.

Develop the concept that the outer membrane of a seed is a protective covering for the food and embryo. Let the pupils discuss that the seed coat separates the food (the cotyledons) and the embryo from the outside environment. This membrane also serves as an insulator. It insulates the contents of the seed from heat and cold. Like other insulators, the seed coat slows down the conduction of both heat and cold into the inside of the seed. See Chap. 45 for detailed experiments that provide evidence that membranes are insulators.

Some pupils may wish to find out whether seeds will germinate if they are exposed to heat and cold. In some regions, annual seeds are subjected to temperatures below the freezing point of water. In other regions, annual seeds are subjected to temperatures above 100°F. In such regions, cultivated annual seeds are harvested and stored until the planting time arrives. Will any of the seeds suggested at the beginning of this inquiry survive, if they are placed in the freezing compartment of a refrigerator or are heated to temperatures of more than 100°F for one school day?

Buy at a food market a bag of black-eyed peas, a bag of lima beans, a bag of popcorn, and a bag of sunflower seeds. Find out whether any of these seeds will survive temperatures below freezing and above 100°F. Because this experiment requires periodic observations over ten days, detailed procedures are given for specific days of the school week.

Procedures

1. Start first lesson on Friday. Divide the class into 12 groups. Give each group a paper towel and 25 seeds. The first three groups should be given lima bean seeds, the next three groups black-eyed pea seeds, the next three groups popcorn seeds, and the last three groups sunflower seeds.

Ask each group to select from the 25 that they think are the best 20 seeds. Wrap these 20 seeds in a paper towel and put a rubber band around the package.

Give each group a card with information like Table 43.1 mimeographed on it. Ask the pupils in each group to write on the card their own names and the kind of seed they have been given.

Reorganize the 12 groups into three large groups. Each of the large groups should be composed of one group that has lima bean seeds, one group that has black-eyed pea seeds, one group that has popcorn, and one that has sunflower seeds.

Discuss the mimeographed cards. Explain that the seeds are to be used in a germination test to find out whether they will develop into plants.

Tell the four small sections of Group 1 that their seeds will be put in a dark place in the room and germinated at room temperature. These seeds will be a control test for Group 2, whose seeds are to be placed in the freezing compartment of a refrigerator and Group 3, whose seeds are to be heated to temperatures above 100°F. Ask Group 1 to write the word *control* on the line on their mimeographed cards to designate the test they are to make. Also ask this group to attach their cards with scotch tape to their paper towel packages. Give Group 1 a paper grocery bag in which to put their four packages of seeds and have the group use a wax pencil to label their grocery bag with the words, *Control Test.*

Tell Group 2 that their group is to find out if their seeds will germinate after they have been in the freezing compartment of the refrigerator. Ask this group to write the word *frozen* on each of their four cards and then attach the cards to their packages of seeds. Also have them put their

Table 43.1
SAMPLE DATA CARD

Experimenters' names Janet, Stanley, Connie
Kind of seed popcorn
Kind of test frozen (Control, frozen, or heated)
Date test is started Tuesday, October 10, 1970

	Date and day of germination				
	#1 Day A.M. Date Oct. 11	#2 Day A.M. Date Oct. 12	#3 Day A.M. Date Oct. 13	#4 Day P.M. Date Oct. 13	#5 Day A.M. Date Oct. 16
Number of seeds germinating	1	13	13	13	13

seed packages in a paper grocery bag and label the outside of the bag *Refrigerated at Temperatures Below Freezing.*

Inform Group 3 that their seeds are going to be heated to temperatures above 100°F. Have them write the word *heated* on their four cards and on the paper bag in which they place their packages of seeds.

2. Second Lesson as Soon as School Opens on Monday. Obtain a metal pan which will fit into the ice cube compartment of the school refrigerator, an electric skillet, and two quarts of either perlite or vermiculite. (Florists use both of these substances in the containers of floral arrangements because these materials absorb enough water to prevent the flowers from wilting while they are being delivered.)

Ask Group 2 to pour one quart of either vermiculite or perlite on the bottom of the pan and to scatter their seeds over the top of the substance. Tell Group 3 to pour the other quart on the bottom of the electric skillet and to scatter their seeds over the top of the substance. Warn both groups to make certain that none of their seeds touch each other. Put Group 2's pan of seeds in the freezing compartment of the school refrigerator. Have Group 3 put the cover on the electric skillet, connect the skillet to the electrical outlet, and turn the switch on the skillet *to the lowest setting.* Continue to cool or heat these seeds until just before school closes for the day.

Give each of the three groups four containers (canned baby food jars are good for this purpose). Have them place the four kinds of seeds in these containers. Label the outside of the containers in accordance with the kind of test that is being made (control, frozen, heated). Cover the seeds in each container with water and let them soak overnight.

3. Third Lesson on Tuesday. Start this experience when school opens. Have each of the three groups remove their seeds from the containers of water and lay them on one end of separate paper towels. Select 16 of the best seeds and discard the remaining ones. Make a test trial to find out whether the paper towel has enough water. Start at the end of the towel on which the seeds have been placed and roll the towel loosely over the seeds. If all of the paper towel becomes moist, do not add any more water. If the paper towel does not become moist, open the towel and sprinkle some water over the seeds. Roll the towel around the seeds again and fold the open ends of the towel toward the middle.

Give each group four plastic sandwich bags and have them place each of the different kinds of seeds in separate bags. Write on the record card the date on which the seeds were placed in the plastic bags. Attach the record cards to the outside of the plastic bags. Place all of the control seeds in the food bag marked *control;* all of the refrigerated seeds in the bag marked *refrigerated*; and all of the heated seeds in the bag labeled *heated.*

4. Fourth, Fifth and Sixth Lessons on Wednesday, Thursday and Friday. Each morning have the three groups count the number of seeds that have germinated and record this number and the date in the spaces provided on the record cards.

Also, appoint one or more pupils to organize a summary chart that can be placed on the bulletin board. Ask each group to record their count on the summary chart after they have recorded their observations on the cards (see Table 43.2).

Make another count of the number of seeds that have germinated on Friday afternoon before the children leave school.

Each time the packages of seeds are opened, it may be necessary to add a little more water. Make certain that the paper towels *are damp but not wet.* If mold appears at any time, remove the seeds from the paper towel, rinse them in a pan of tap water, and rewrap the seeds in a clean damp paper towel. When the seeds are examined on Friday afternoon, make certain that the paper towel in which the seeds are wrapped is *moist.*

5. Seventh Lesson on Monday. Check the seeds for the last time. If the kinds of seeds suggested were used, all of the seeds which are going to develop should have germinated. Ask each of the three groups to record their final count on the mimeographed card and on the summary chart on the bulletin board.

Discuss the results of the germination tests. Compare the number of seeds that germinated in the three groups (control, refrigerated, and heated). What effect did cooling or heating have upon the *length of time* it took the seeds to germinate or the *number of seeds* that germinated? (If the pupils' results are similar to those in the sample summary chart (see Table 43.2), they would be correct in stating that neither short periods *of freezing temperatures* nor *of*

Table 43.2

SAMPLE SUMMARY CHART

	Black-eyed peas					Lima beans					Popcorn					Sunflower				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Group 1 (control)	0	15	15	15	15	0	0	12	14	14	0	8	9	9	9	4	11	13	13	13
Group 2 (frozen)	2	13	15	15	15	0	13	15	15	15	1	13	13	13	13	11	12	12	12	12
Group 3 (heated)	15	16	16	16	16	7	15	16	16	16	1	11	14	14	14	6	8	9	9	9

temperatures above 100°F seemed to affect the *rate of germination* and *the number* of these annual seeds *that germinated.*) From this test, they could also state that it seems likely that seeds do have adaptations that enable them to survive both heat and cold.

Also experiment to discover whether such substances as wax, lacquer, and lightly glazed paper *actually are insulators.* (These substances are similar to the ones the pupils both saw and felt when they examined the membranes of the seeds.) Obtain two packages of party cups that are used for candies and nuts. (They are also called soufflé cups.) When the experiment is set up, invert one cup on top of the other because the seed coat completely covers the seed. Fasten the two cups together with a rubber band. Use three of the lightly glazed party cups with their inverted cover *as a control.* Use clear nail polish to lacquer the inside and outside of six cups (three for the cups and three for the covers). Also coat six cups with melted paraffin. (Caution the pupils about working with melted paraffin. It will ignite if it gets too hot. This can be avoided by placing the paraffin in a metal container and heating the container in a pan of water. For heat use either an electric stove or a coffee warmer, because either can be regulated for low heat. *Do not use an open flame.*) Use forceps to hold the cups when they are dipped into the paraffin.

Fasten together with rubber bands each of the three sets of cups and their covers. Pry the cups and their covers far enough part to pour a measured amount of water (one tablespoon is suggested) into each of the nine cups. (The cups are too flimsy to permit pouring the water before the cups and their covers are fastened together.)

Place the cups in two metal ice cube trays and put the trays on the bottom of the freezing unit in the refrigerator. Check the experiment at intervals of 30 minutes. In which set of cups—the lightly glazed, the lacquered, or the waxed—does the ice begin to form first? (In the lightly glazed cups.) Next? (In the waxed cups.) Last? (In the lacquered cups.) Develop the concept that insulators are poor conductors of heat or cold. What did we find out from this experiment that seems to show that seed coats are insulators? (Both lacquer and wax kept out the cold for a longer time than the lightly glazed paper.) Which one of the three insulators tested in this experiment was the best? (The lacquer.) Why? (Because it kept the cold out for a longer time than the other two substances.)

When discussing that seed coats are insulators that protect the baby plant (embryo), emphasize that the seeds selected for testing were large ones and that they were produced by plants that have been either developed or introduced by man. For this reason the mature seeds of these plants are commonly harvested, stored, and protected from the long periods of heat or cold that occur during dormant seasons. Pupils who live in rural areas may be able to report instances, in which some seeds have survived outdoors through a very cold or a very hot dormant season and germinated during the following growing season.

Children who live in mild climates (where many plants grow throughout the year) have opportunities to observe that such annual plants as marigolds, petunias, snapdragons, zinnias, and so on wither and die a short time after they have blossomed even though the temperatures are mild. A few months later, after the dormant season ends for this region, dozens of tiny plants will emerge from the soil where the parent plant grew. These tiny plants have germinated from seeds that were produced by the parent plant.

Emphasize the fact that many wild annual plants, particularly the so-called weeds, grow *from small seeds* which survive the dormant season. They grow wherever they happen to fall on the ground. Their small size may be a useful adaptation, because small seeds are more likely than large seeds to be covered with such insulators as soil and leaves. The tiny seeds of cultivated annual plants, like petunias, poppies, cosmos, and forget-me-nots, also commonly survive cold or hot dormant seasons outdoors and germinate during the next growing season.

Find out whether the pupils know the function of the remainder of the substance that is inside the seed. (They may say that it is food.) Why is the food that is stored in the seed an adaptation that enables the seed to survive? (The tiny plant embryo in the seed cannot grow without food. The food stored in the seed is used by the young plant until it can manufacture its own food.) Why can the tiny plant not make its own food? (A very young plant does not have chlorophyll. Chlorophyll is essential for food making.) What color is the embryo that is inside the seeds? (It is either colorless, white, or a very light shade of yellow.) What color is the seedling for the first few days after it germinates? (It is the same color as the embryo.) What color is the seedling when it begins to manufacture its own food? (It is green.) See Chap. 45 for detailed experiments that identify the classes of food stored in a seed. This chapter will provide further evidence that this stored food is also an insulator.

2. How do biennial plants differ from annual plants? How are the underground parts of biennials classified? What adaptations do biennials have that enable them to survive a dormant season?

In Chap. 42 the children learned that plants that *die* at the end of the growing season are called *annuals* and that new annuals are grown each year from the seeds produced by these plants. Also they will have seen in the flower garden some plants whose *aboveground parts die back to the ground* at the end of the growing season, leaving *underground parts alive* to survive one or more dormant seasons. These plants, like annuals, can be grown from seed; but they also can produce new stems, leaves, and blossoms from these surviving underground parts. These plants are classified as either *biennials* or *perennials.*

The pupils will have separately listed by name many of the garden annuals. They will have listed in one category the biennial and perennial plants they observed in the garden, because no attempt was made in Chap. 42 to distinguish one from the other. It is the purpose of this inquiry and the next one to explore the distinguishing characteristics of plants which are classified as *biennial* and *perennial* herbs (see Table 43.3).

Find out whether the pupils know why some plants are called *biennials.* (It takes *two growing seasons* for biennials to grow from seed, blossom, and produce more seeds. Annuals grow from seed, blossom, and produce more seeds *in one growing season.* At the *end of the first growing season,* the leaves and stems of biennials die back to the ground. The *underground parts* of biennials *remain alive through the first dormant season.* At the *end of the second growing season, all of the old parts* of a biennial plant usually die, just as do all of the parts of annual plants at the end of *one* growing season.)

Because the underground parts of biennials remain alive through the dormant season, the pupils should examine them carefully for adaptations for survival. Collect the underground parts of such biennial plants as carrots, onions, white potatoes, turnips, parsnips, gladioluses, crocuses, and hyacinths. If observations of the growth of new biennial plants from these underground parts are also to be made, try to obtain parts several months after they have been harvested. The buds on the underground parts of many kinds of biennials *will not grow* until they have been dormant for a period of time, lasting from several weeks to several months.

Ask the pupils to examine this collection for *common characteristics,* which may be clues to the ability of these plants to resume growth at the end of the dormant season. [They have two common characteristics. (1) They each contain

Table 43.3

SOME GREEN PLANTS WHICH GROW IN EITHER NORTHERN OR SOUTHERN REGIONS

Annual Plants (one-year life cycle)	Biennial Plants (two-year life cycle)	Perennial Plants (many-year life cycle)	
Herbs (fleshy tissue)			Trees and Shrubs (woody tissue)
Annual Herbs	**Biennial Herbs**	**Perennial Herbs**	**Perennial Trees and Shrubs**
At the end of *every* growing season, *both aboveground and underground parts die.*	At the end of the *first* growing season, *only the aboveground parts die.*	At the end of *every* growing season, the *aboveground parts die.*	*Both aboveground* trunks, stems, branches and *underground* roots *remain alive year after year.*
	At the end of the *second growing season, both aboveground and underground parts die.*	At the end of *every* growing season, there are *underground parts that remain alive.*	
List of Annual Herbs	**List of Biennial Herbs**	**List of Perennial Herbs**	**List of Perennial Trees and Shrubs**
aster (c),* (annual kind)	amaryllis (c)	ageratum (c) (grown as an annual in climates that have a dormant season) anemone; Japanese (c) artichoke (c) asparagus (c) aster (c + w) (perennial kind)	angel's trumpet (c) azalea (c + w)
baby's breath (c), (annual kind) bachelor's button (c) balsam, yellow (c) bean (c) black-eyed pea (c) blankct flower (c)	beets (c) broccoli (c) brussels sprout (c)	baby's breath (c) (perennial kind) banana (c) baneberry, white (w) begonia, wax (c) (grown as an annual in certain climates) bellwort (w) bird-of-paradise (c) (banana family) bleeding heart (c) bloodroot (w) bluet (w) bunchberry (w) buttercup (c + w)	bignonia (c) bottle brush (c) bougainvillea (c) bridal wreath (c)
calendula (c) calliopsis (c) (an annual coreopsis) candytuft (c) corn (c) cosmos (c) (grown as a biennial in climates that do not have a cold dormant season) cucumber (c)	cabbage (c) camassia (c) Canterbury bell (c) carrot (c) cauliflower (c) celery (c) chiondoxa (c) crocus (c)	calla (c) cattail (w) checkerberry (w) Christmas rose (c) clover (c + w) columbine (c + w) composite family (c + w) aster daisy goldenrod Joe-pye-weed tansy thistle	cactus (c + w) camelia (c + w) cherry; Japanese (c) coco plum (c) crape myrtle (c) croton (c)

***Table 43.3* (*cont.*)**

Annual Herbs	Biennial Herbs	Perennial Herbs	Perennial Trees and Shrubs
		coolwort (c) coreopsis (c) (perennial kind) cowslip (w) creeping wintergreen (w)	
	daffodil (c) dog tooth violet (w)	dahlia (c) daisy (c) African gerbera shasta delphinium (c) digitalis (c) Dutchman's breeches (w)	dogwood (c + w)
eggplant (c)	Eastern quamash (c) endive (c)		
flowering tobacco (c) forget-me-not (c) (annual kind) four o'clock (c)	freesia (c) fritillary (c)	false mitrewort (c) false solomon's seal (w) false spikenard (w) forget-me-not (c) (perennial kind, grows as a biennial in climates that have a dormant season) foxglove (c) foxglove; wild downy (w)	flowering almond, crab, apple, quince (c) forsythia (c) frangipani (c)
gaillardia (c) (annual kind) gourd (c) (grown as a biennial in climates that do not have a dormant season) gypsophila (c) (annual kind)	garlic (c + w) gladiolus (c) grape hyacinth (c)	gaillardia (c) (perennial kind) gerbera daisy (c) ginger family (c + w) gypsophila (c) (perennial kind)	gardenia (c) geranium (c) (cuttings are grown as annuals in climates that have cold dormant seasons)
	hyacinth (c)	heliconia (c) hepatica (w) hollyhock (c) (grown as a biennial in climates that have cold dormant season)	hibiscus (c) honeysuckle (c) hydrangea (c)
		Indian turnip (w) iris family (c + w)	ivy; Virginia creeper, Boston (c + w) ixora (c)
Johny-jump-up (c)	jonquil (c)	Jack-in-the-pulpit (w)	jasmine (c) jatropha (c)
larkspur (c) lima bean (c) lobelia (c)	leek (c + w) lettuce family (c) lily (c) amaryllis belladonna crinum day	lobster claw (c) lupine (c + w)	lantana (c) lilac (c)

Annual Herbs	Biennial Herbs	Perennial Herbs	Perennial Trees and Shrubs
	meadow rain regal spider		
marigold (c) melon (c) morning glory (c) moss rose (c)		mandrake (w) marsh marigold (w) May apple (w) milkweed family (c + w) mint family (c + w) peppermint spearmint monkey flower (c + w) monkshood (c + w)	mock orange (c) myrtle; blue (c)
nasturtium (c) nicotiana (c)	narcissus (c)		
		orchid family (c + w)	oleander (c)
pansy (c), (annual kind) pea (c) pepper (c) petunia (c) phlox (c), (annual kind) pink; cottage (c) popcorn (c) portulaca (c) pumpkin (c)	pansy (c), (biennial kind) parsley (c) parsnip (c) potato; white (c)	painted tongue (c) peony (c) phlox; hardy, summer, ground (c), (perennial kind) pineapple (c) pink family (c + w) poppy; California, Oriental (c) (grown as an annual in climates that have a dormant season) potato; sweet (c)	palm—all kinds (see Table 44.2) pentas (c) periwinkle (c) poinsettia (c) powder puff (c) pussy willow (c + w)
	radish (c) rutabaga (c)	rhubarb (c) rue (c + w)	rhododendron (c + w) rose (c + w)
scabiosa (c) snapdragon (c) squash (c) stock (c) sunflower (c) sweet alysium (c) sweet pea (c) sweet sultana (c)	salsify (c) scilla (c + w) Siberian squill (c) snapdragon (c) snowdrop (c) spinach (c) sweet william (c)	salpiglossis (c) (grown as an annual in some climates) shrimp plant (c) skunk cabbage (w) snapdragon (c) spotted wintergreen (w) spring beauty (w) squirrel corn (w) sweet pea (w)	spirea (c) Surinam cherry (c) syringea (c)
tomato (c) touch-me-not (c)	tuberose (c) tulip (c) turnip (c)	toadflax (w) torch lily (w) trillium (w)	trees—all kinds, see Tables 44.1 and 44.2
verbena (c) viola (c)		violet family (c + w)	
	water hyacinth (w)	watercress (c + w) water lily (c + w) water plantain family (w) windflower (c + w) wood anemone (w)	
zinnia (c)			

*Table includes both cultivated (c) and wild (w) plants.

stored food for the plant's second season of growth. See Chap. 45, Inquiry 6 for food tests on seed meats. The same procedures can be used to identify the classes of food stored in the underground parts of biennials. Cut several slices through the different biennials to expose the interior in which the food is stored. See Chap. 45, Inquiry 6 for detailed directions for identifying the different classes of foods. (2) Each contains buds, sometimes called eyes, which, *during the second year*, will grow into new *stems, leaves, and blossoms.*]

Place one of each whole underground part of the biennials examined in a plastic bag containing either moistened peat moss, perlite, or vermiculite. Seal the bags. Place these packages in double grocery bags, on which are recorded the plant's name and the date the experiment began. The double grocery bags reproduce the dark underground environment in which these parts normally develop. Every few days, open the grocery bags and look for *developing buds* on the biennials in the plastic packages. If mold or rot appears, open the plastic bag, remove the mold, and cut away the rotted area. Leave the plastic bag open for a few days, and then return it to the paper bag. When the mold and rot do not reappear, reseal the plastic bag. When growth appears, *identify the area* of the underground part where buds have developed. Pupils should be able to make these observations.

1. The *buds* grow only from *a small area at the top* of carrots, turnips, and parsnips. The rest of the surface produces fine white roots.
2. The *buds* grow *almost any place* on the round fleshy underground parts of gladioluses and crocuses. Roots emerge only from the small base area.
3. The *buds* are *inside and attached to the small base area* of the underground parts of onions and tulips. When the buds grow, they will emerge from the top. Roots will grow only from the small base area.
4. White potatoes have buds (eyes) formed in a spiral around the potato. The buds are usually more concentrated near one end.

Help the pupils to understand why the underground parts of carrots, turnips, parsnips, and so on, are called rootstalks. (They have a *large root area* containing stored food and a *short thick stalk* (*stem*) *area* at the top, from which buds develop.)

Pupils should also learn that the solid, round fleshy underground parts of gladioluses, crocuses, and so on, are underground *stems* which are called *corms.* The food is *stored in this fleshy stem* and the buds develop from it (see Fig. 43.2).

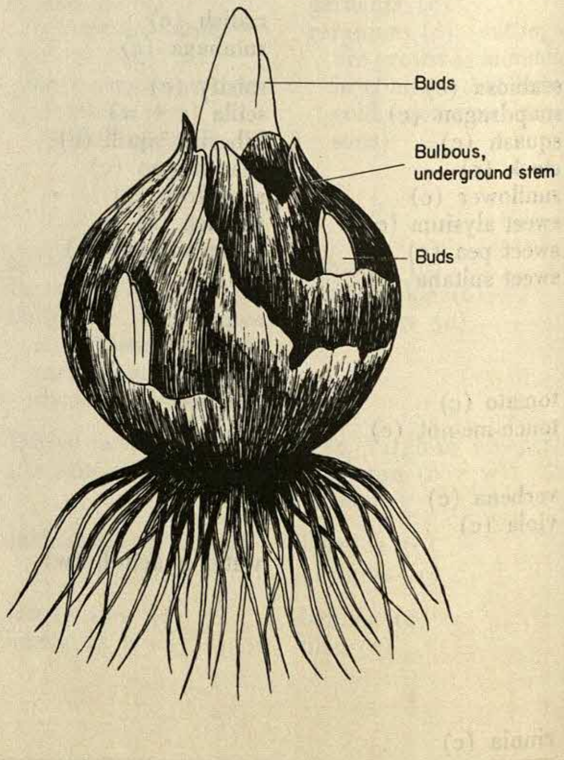
The mature underground parts of onions and hyacinths are also *stems.* They are very short basal stems surrounded by fleshy leaf scales. The food is stored in the leaf scales. These underground parts are called *bulbs* (see Fig. 43.3).

The white potato is another modification of a *stem.* It is called a *biennial tuber.* Biennial tubers are thickened extensions of underground stems, which contain stored food. Buds develop from this stem (see Fig. 43.4).

See Table 43.4 for comparisons of biennial rootstalks, bulbs, corms, and biennial tubers.

Help the pupils to see that the underground parts of biennials called corms, bulbs, and biennial tubers are *three modified forms of stems* and that underground rootstalks are *modified roots* with *a small stem area.* They should be able to conclude that (1) biennials survive the dormant season because they have modified underground

Fig. 43.2 Solid bulbs, or corms. Such biennial plants as the crocus, the jack-in-the-pulpit, or Indian turnip, and the cyclamen develop solid bulbs or corms; buds develop anywhere on the radial lines.



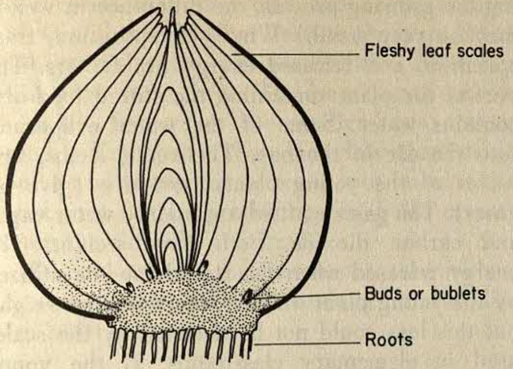


Fig. 43.3 A bulb cut longitudinally to show the spiral arrangement of the thick, underground leaf scales around the underground stem. Such biennials as chives, garlic, wild leeks, onions, tulips, hyacinths, jonquils, and narcissuses develop bulbs similar to the one illustrated. New bulblets develop in the axil of the fleshy leaf scales.

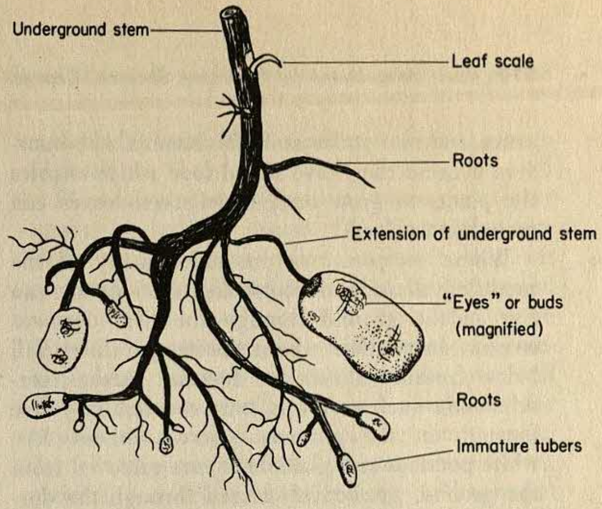


Fig. 43.4 Biennial tubers. Such biennial plants as Southern nut-grass, Jerusalem artichoke, and the Irish, or white potato develop tuberous extensions of underground stems similar to the ones illustrated.

Table 43.4

COMPARISON OF UNDERGROUND PARTS OF BIENNIAL AND PERENNIAL PLANTS

Name	Location of Stem	Where Food Is Stored	Where Buds Form	Produce and Grow From	Classification
Rootstalk Examples: carrot turnip	small area at top of fleshy root	fleshy root	stem area	seed	biennial
Bulb Examples: tulip, onion	small basal area of bulb	fleshy leaves	stem; buds surrounded by fleshy leaves	seed, bulblet	biennial
Corm Examples: crocus, gladiolus	solid round stem (corm)	fleshy stem	surface of corm	seed, small corm	biennial
Biennial tuber Example: white potato	fleshy extensions of underground stem	fleshy stem	scattered over tuber; more on one end	seed, tuber	biennial
Perennial tuber Examples: dahlia, peony, sweet potato	stem or stem area at top of fleshy root	fleshy root	stem	seed, new stems and fleshy roots	perennial
Rhizome Example: iris	solid fleshy fibrous part, sometimes prostrate or creeping	fleshy stem	rhizome	seed, new rhizome	perennial
Crown Example: chrysanthemum	at or just below surface of the soil	stem	stem	seed, new underground stem	perennial

stems and root stalks and (2) biennials also survive because they have stored food which enables the plants to grow until their green leaves can manufacture food.

Where temperatures are mild, many of the modified stems and rootstalks of biennials can live in the ground through the first dormant season. In regions where the temperatures fall below freezing during the dormant seasons, certain ones, such as tulips and crocuses, may live through in the ground; whereas others, like white potatoes and gladioluses, are removed from the ground, protectively stored through the dormant season, and replanted at the beginning of the next growing season.

Some pupils may wish to discover whether the food stored in the underground parts of biennials is used by the plant that grows from them. They should be able to plan an experiment in which the size of the bulb, corm, biennial tuber, and rootstalk is carefully measured and recorded. An onion *bulb*, crocus *corm*, white potato *biennial tuber*, and a carrot *rootstalk* may be used. Seal each in a plastic bag about half full of either moistened peat moss, perlite, or vermiculite. Weigh each *in its bag*. Record the weight. Place the plastic bags in double grocery bags. As soon as the buds begin to develop, check and make daily observations and records. Watch for and remove mold and rot. Treat for these conditions as suggested earlier. If rot is removed, weigh the removed material and record this loss of weight.

Keep a record of the changes that occur. Note whether the roots or the stems develop first. (The roots usually develop first.) When the stems are at least an inch long, remove the paper bags and place the plastic bags near a window. Observe the change in the color of the stems and leaves after the plants have been in sunlight for several days. (The stems and leaves will change in color from yellow to green.)

After the plants have developed green leaves, weigh the plants in the plastic bags. Record this weight. Carefully remove the plants from the growing material and compare the size of the underground part with its original size. What evidences are there that the young plant used the food contained in the corm, biennial tuber, bulb, and rootstalk? (In each case there should be a decrease in the size. There may also be loss in weight. If the plastic bags were not opened during the growing process, the difference in weight may be very small.) Why? (Evaporation, transpiration, and released energy are factors. The part of the plant containing the stored food also contains water. Some of the water evaporates into the air in the bag. The roots, stems, and leaves of the young plants transpire (give off gases). The gases emitted are mainly water vapor and carbon dioxide. Both have weight. The energy released when the stored food is utilized by the young plant would cause a loss in weight, but this loss could not be detected by the scales used in elementary classrooms. If the young plant, water vapor, water that condenses in the bag, carbon dioxide, and heat loss were weighed, the weight should be approximately equal to the weight at the beginning of the experiment.)

Make bar and line graphs of the data collected during the previous experiment. Graphs can be made to show changes in size, weight, time-lapse between the date the experiment began and time the roots developed, time-lapse between the appearance of roots and stems. Also, graphs could be made to compare the rate of growth of the roots with that of the stems.

Let the pupils plant one or more kinds of biennial seeds, such as onions, chives, carrots, red beets, and so on, in the potting mixture described in Inquiry 2, Chap. 42. Observe the growth of these plants for several months. Then, pull the plants from the soil and observe the development of the underground stems and roots. (The young underground stems and roots will look like miniatures of the mature ones.)

Find out whether any of the pupils have seen the blossoms of such plants as carrots, beets, onions, chives, parsley plants, and radishes. Some of them may have seen chive and onion plants in blossom. Discuss why they do not see carrot, beet, and radish blossoms. (They are usually grown for only one growing season for the food in the underground root. They are harvested during the first growing season. Their blossoms can only be seen where these plants are grown through their complete two-year cycle, in order to harvest their seeds.)

Obtain permission to remove some daffodils, tulips, and gladioluses from a garden. Take these to the classroom to observe their bulbs and corms. Note that a number of tiny bulbs or corms are clinging to the larger bulbs and corms. It is also possible that there will be old bulbs and corms that have died and begun to decay. What will the gardener do with these small bulbs and corms? (He will plant them. New plants will grow from them. The larger ones will blossom the first year; the smaller ones, the next year.) Emphasize that biennials that develop bulbs and corms reproduce in two ways: (1) by seed, and (2) by producing new bulbs or corms from the old bulb or corm.

Discuss some of the reasons why biennials can live in so many different kinds of climate. There are several reasons:

1. The parts of the plant that remain alive during dormant seasons are insulated from both heat and cold by outer membranes.
2. The parts of the plant that remain alive are insulated from both heat and cold by the soil.
3. There is sufficient food stored in the underground parts of biennials to produce a new plant that will grow, blossom, and bear seeds.

3. Why are some kinds of plants called perennials? How do perennials differ from biennials? How are the underground parts of perennials classified? What adaptations do perennials have that enable them to survive dormant seasons?

If the children have had the experiences suggested in the previous inquiries in this chapter, they will have learned that at the end of its first growing season, a *biennial plant* dies back to the ground and that, at the end of its second growing season, all of the old parts of the plant die. In their visits to gardens, they will have observed *plants other than biennials,* which die back to the ground at the end of the growing season. However, *growing season after growing season,* these plants come up from underground parts. Ask the pupils to suggest a name for such plants. It is possible that among the suggestions, there will be the term *perennial.*

Find out whether the children know the meaning of the term *perennial.* Encourage them to make their own definitions before they check dictionaries and reference books. (The first syllable, *per,* means *through*; and the two syllables, *anni,* mean *years.* Perennial literally translated means *through the years.* They are called *perennial plants* because year after year new growth appears.)

Biennial plants have underground parts that survive a dormant season. Do perennial plants also have underground parts that survive dormant seasons? Are there buds on their underground stems too? Is food stored in an underground part? Ask a gardener for small clumps of perennial plants. Clumps of peony, dahlia, iris, and chrysanthemum would be good specimens for pupils to examine. They should be able to make the following observations and statements. Irises, peonies, and dahlias have a fleshy underground part, which may contain stored food. This can be checked by using the food tests previously recommended. Buds can be found on all four specimens. Because buds form only on stems or stem areas, all four specimens contain a form of underground stem. These characteristics are the same ones that enable the underground parts of biennials to survive a dormant season. They should also enable a perennial plant to survive. How do they, however, enable a perennial plant to survive *many dormant seasons*? Ask the pupils what they think may enable perennials to do this. [They should be able to make two guesses: (1) The underground parts do not die at the end of the second growing season. (2) If the underground parts do die, they must have produced new underground stems before they died.]

Examine the clumps for evidence that some underground parts have died and that other new underground parts have formed to replace the dead parts. (Both old dead parts and new live ones can be found in these underground clumps of perennials. The dead parts will appear darker, feel softer, or may be drier or more brittle. The buds are on the live underground stems or stem areas.) How do the underground parts of perennials differ from the underground parts of biennials? (The new underground stems of perennials are extensions of the old stems and remain attached to the old stem. The underground stems of biennials also produce new stems, but the new stems *separate* from the old stem and become independent plants.)

Discuss why a gardener digs and divides (either cuts or pulls apart) the large clumps of perennials every few years and then plants the smaller clumps. (The underground parts multiply and become overcrowded.) Notice the tangled

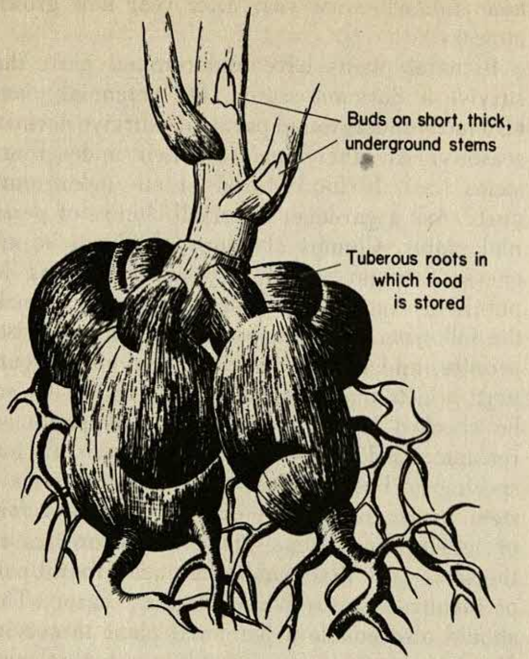

Buds on short, thick, underground stems
Tuberous roots in which food is stored

Fig. 43.5 Perennial tubers. Such perennials as the dahlia, peony, and sweet potato develop from this kind of tuber. Even though the tuberous roots of these plants live for only a little longer than a year, they are classified as perennials because the same underground stem continues to live year after year.

and crowded condition of the underground parts of the four clumps of perennials studied.

Have the pupils separate their collections of perennial clumps into different groupings. This separation should be based upon the likenesses and differences between the underground parts. How are the underground parts of dahlias and peonies alike? Where does the food appear to be stored in them? (They both are tuberous roots on which there is either a stem or stem area containing buds. Food is stored in the tuberous root.) Ask the pupils to suggest a name to classify the underground parts of these perennials. (They should suggest *perennial tuber*. See Fig. 43.5.)

How does the underground part of an iris *differ* from the perennial tuber of a peony and dahlia? (The dahlia and peony have thickened underground *roots* containing stored food. The iris has a thickened underground *stem* containing stored food.) If the pupils do not know that gardeners call these *rhizomes*, supply this name (see Figs. 43.6, 43.7, and 43.8.)

Help the pupils to see why gardeners refer to the underground parts of chrysanthemums as a *crown*. (It is a round, dense crown of short tangled new and old stems near the surface of the ground. Buds are on the live stems.) See Table 43.4 for comparisons of *rhizome, perennial tuber, and crown.*

What *adaptations* do rhizomes and perennial tubers have that enable them to survive dormant seasons? Observe both the outer membrane and the interior tissue of such perennials as cannas, callas, peonies, dahlias, and irises. These perennials are suggested because their underground parts are large and easy to examine. The rhizomes of iris are discussed in this development because different varieties of iris grow in the middle latitudes, in the subtropics, and in the tropics. Cut several rhizomes both vertically and horizontally. Note that both the membrane and the inner tissue are very tough and fibrous. Put several cut pieces of a rhizome in a mortar and try to crush it with a pestle. A hammer and a board can also be used for this purpose. The tissues are so tough that it may be necessary to cut them into very small pieces before they can be crushed. Note that there seems to be only a small amount of fluid present in this fleshy stem.

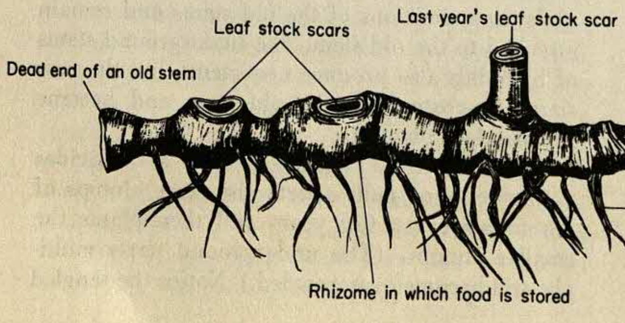

Last year's leaf stock scar
Leaf stock scars
Dead end of an old stem
Bud
Roots
Rhizome in which food is stored

Fig. 43.6 The rhizome of a perennial. This particular rhizome consists of a thickened, underground stem, one strong bud, and roots. Each year when the new underground stem produces new leaves, blossoms, and roots, the old underground stem dies. Such perennials as the iris family, false Solomon's seal, and true Solomon's seal form thickened, gnarled, runner-like rhizomes similar to the one shown.

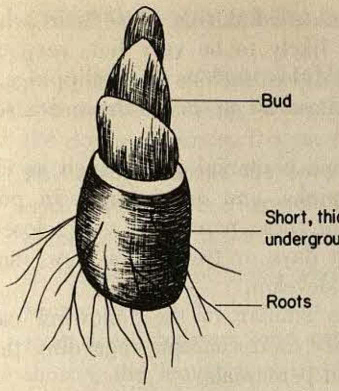


Fig. 43.7 Another type of rhizome developed by some perennials. The short, thick underground stem of such perennials as the Trilliums (large, white, purple, dwarf white, and painted) is about one inch long. The mature rhizome dies after it has blossomed and formed a seed and new rhizome. The new rhizome does not fully mature until mid-summer.

How can it be determined whether the liquid in the mortar is water, or oil, or both? (Crush the stems on a folded paper towel. If the spot made on the towel disappears, it is caused by water. If the entire spot remains, it is caused by oil. If part of the spot remains, both water and oil are present.)

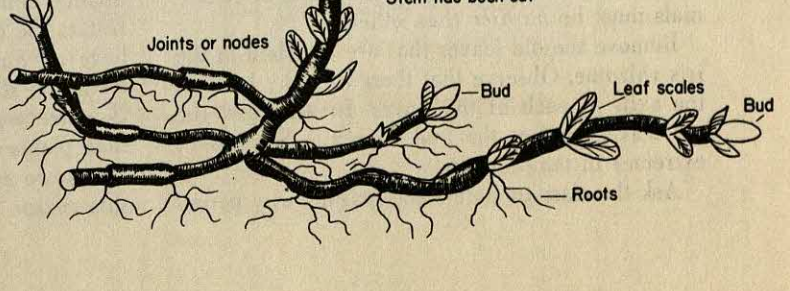
How can the hard tough condition of the membrane and inner tissue of the rhizome and the small amount of fluid in it be an adaptation for survival? (The characteristics of hardness and toughness may serve as insulation from sudden temperature changes. The lack of fluid may allow the rhizome to be frozen without tissue damage from ice crystals. If the rhizome dies, the food supply for the bud is destroyed.)

Have the pupils use magnifying glasses to examine the underground stems of perennial plants for buds, which will develop into mature plants during the next growing season. Notice how far the bud is below the surface of the soil. (The buds of some perennial plants are *very close to the surface of* the soil. Others have buds *from three to five inches below the soil's surface.*) Examine the size of the bud. (Some perennials have *very tiny buds.*) Notice too whether the buds *protrude from, are flush with,* or *are recessed and nearly submerged* in the stem. (The buds of some perennials *are submerged* in the stem.) Examine the bud's outer membrane. Remove the membranes from some buds. (The buds of some perennials are covered by *several layers of protective membranes called scales.*)

Encourage the pupils to speculate how the bud's protective membrane, location, and size may be adaptations to enable it to survive dormant seasons. They may make statements similar to these: (1) The outer membranes that protect the buds of perennial plants may *insulate* the bud. (2) Buds may be protected from either heat or cold by being very tiny and by being submerged in the stem. (3) The depth below the soil at which the buds form may be an adaptation that enables them to survive dormant seasons.

Why are the outer membranes that cover buds on some perennials better insulators than others? Have the children examine the outer membranes of several different kinds of perennial buds. What characteristics should outer membranes have to make them good insulators? Should they be porous or nonporous, dry or wet, thick or thin, dark or light in color? These questions can be answered by considering the functions of the outer membrane and by examining these membranes carefully. [Some of the functions of outer membranes are: (1) to limit the amount of water either from entering or from leaving the

Fig. 43.8 A third type of rhizome developed by some perennials. Such perennials as the mint family, Scotch rose, and couch-grass, or quack grass, develop long, slender, underground stems called *runners*. This simple type of rhizome grows very rapidly and lives longer than some rhizomes do. If this rootstock is cut into pieces, almost every piece will produce one or more new plants.



bud, (2) to reduce heat loss in the bud, and to regulate temperature changes between the bud and the soil or between the bud and the air in the soil. A perfect insulator for buds on underground stems would be a membrane that is nonporous, dry, and thin enough to be pushed aside when the bud develops. The correct color would depend upon climatic conditions. In climates that have severely cold dormant seasons, a dark color would absorb more heat than a light color. In dormant seasons that are hot, a light color would absorb less heat. The outer membrane is very frequently the same color as the outer covering on the stem. The nonporous membrane that covers the bud also helps to regulate the amount of water that enters or leaves the bud.]

Why may the very tiny size and the submergence of some kinds of perennial buds be an adaptation for surviving the dormant season? Have the pupils notice that several different kinds of perennials have buds so small that they are barely visible. They may also be recessed in the underground stem. How can these characteristics enable the bud to survive? (This adaptation reduces the amount of bud surface exposed to the exterior environment. A reduction in exposed surface area decreases the probability that the buds will be damaged by climatic factors.)

Why is the depth below the soil's surface, at which a bud forms, an adaptation for survival? (Buds that form three to five inches below the soil may be better adapted to survive heat and cold because they are insulated by the soil.) However, pupils may point out, that the buds of chrysanthemums, which are close to the surface of the soil, do survive cold, dormant seasons. They can see also that peony and dahlia tubers have buds the same distance below the surface. They will know too and wonder why peony tubers survive cold dormant seasons in the ground, while dahlia tubers are dug and protected in a cool dry place through the same kind of cold dormant season. Discuss what other factors may be involved. (Some kinds of perennials must be *hardier* than others.)

Remove the old leaves that are attached to the iris rhizome. Observe that there are tiny buds in the axils of each of the leaves. In this case, the old leaves protect the bud from the hazards of extremes in temperature.

Ask the class to state some reasons why perennials are *mulched* during periods in which the weather is likely to be very hot, very cold, or very dry. (Mulch, such as grass clippings, leaves, and peat moss is an insulator and also holds water.)

Plant some perennial plants such as chrysanthemums, pinks, and quack grass in pots. Cut the stems of these perennials very close to the soil. In ten days or two weeks, new stems and leaves will develop.

Questions similar to the following can help pupils clarify their concepts regarding the characteristics of perennials.

1. When new lawns are being developed, why are grass *sprigs* instead of seed or sod, sometimes planted? (The underground stems of certain kinds of perennial grass multiply and spread very rapidly.)
2. Why will cuttings (slips) from the above ground stems of many kinds of perennials root and produce new plants? (The above ground parts of many kinds of perennials contain buds that will develop into *roots*, branches, leaves, and blossoms.) Try to root several kinds of cuttings from perennials *in water* and *in soil.* Why is it better to use an opaque rather than a transparent water container? (Roots develop better in darkness than they do in light.) Devise experiments to discover if root hormones decrease the length of time its takes roots to develop on potted cuttings. (In some cases, the hormones do decrease the rooting time. In other cases, roots develop faster without them.)
3. How are perennial and biennial plants alike? How are they different? Both have underground parts containing stored food. Both have underground stems on which there are buds. Biennial plants complete their life cycle in two years. Perennials live for many years.

Find out if the pupils know why annuals, biennials, and some kinds of perennials are classified as *herbs.* Check their statements with the dictionary definition of an herb. Have the children restate the definition in their own words. (Herbs have *no bark and no woody tissue.*) Perennial trees and shrubs have bark and woody tissue, *so they are not herbs.* Annual, biennial, and perennial plants (with the exception of shrubs and trees) do not have bark or woody tissue. For this reason they are called herbs.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. A seed is composed of a seed coat, stored food, and the plant embryo. The seeds of many kinds of plants have adaptations that enable them to survive the dormant season. The seed's outer membrane is an insulator that protects the tiny embryo inside the seed from its outdoor environment and from both heat and cold. A seed contains the food necessary for the growth of the plant embryo until it is large enough to manufacture its own food.

2. Some kinds of plants which die back to the ground at the end of the growing season are called biennials. It takes two growing seasons for biennials to grow from seed, blossom, and produce more seeds. At the end of the first growing season, the leaves and stems of biennials die back to the ground. The underground parts of biennials remain alive through the first dormant season because they have adaptations that enable them to survive. At the end of the second growing season, all the old parts of a biennial plant usually die.

The underground stems of some kinds of biennials are called *bulbs.* A bulb is a short underground stem containing buds, which are surrounded by thick leaves in which food is stored.

The underground stems of some biennials are called *corms.* A corm is a round thickened stem in which food is stored. The corm develops one or more buds on its surface. A corm is sometimes called a solid bulb, although it is not a true bulb because it does not have thickened leaves.

Some kinds of biennials develop thickened extensions of their underground stems which contain stored food. These are called *biennial tubers.* Buds on the tubers develop into new plants.

Other kinds of biennials produce fleshy roots with short thick stems and are called *fleshy rootstalks.* They, too, contain stored food and have buds.

Biennials that produce bulbs, corms, and biennial tubers can reproduce in two ways. They can be reproduced from seeds and from new bulbs, corms, and tubers that develop from the old underground part. Biennials that produce rootstalks are grown from seeds.

The underground parts of biennials are adaptations that enable them to survive dormant seasons.

3. The leaves and stalks of perennial herbs die back to the ground each year. The underground parts of perennial plants contain enough food to enable the buds to develop into plants that can manufacture their own food.

Perennial herbs develop new underground buds, stems, and roots every year. The new underground stems or roots of perennials are extensions of the old parts. The new parts remain attached to the old parts. The underground parts of perennial herbs multiply. The buds on the underground parts of biennial herbs develop into independent plants. The underground parts of perennials must be divided every three or four years to avoid overcrowding. Some kinds of perennial plants are hardier than others.

Perennial herbs have adaptations that enable them to survive dormant seasons. Some of the adaptations are the following: underground food storage in hard tough tissues, membranes that insulate the bud and the food source, tiny buds and submerged buds lower the surface area exposed to the outside environ-

ment, and buds protected by the depth below the soil surface at which they form.

Cuttings from the aboveground stems of many kinds of perennials will root and produce new plants.

Herbs have no bark and no woody tissue. The aboveground parts of annual, biennial, and perennial plants that die back to the ground each year are classified as herbs. The stems and roots of perennial trees and shrubs continue to live for many years.

Chapter Forty-Four

Trees, Shrubs, and Plant Communities Around the World

INQUIRIES

1. How can the stems of shrubs and the branches and trunks of trees survive through prolonged periods of heat and cold? Why do the aboveground stems of biennial and perennial herbs not survive? Why are the buds of trees and shrubs an adaptation for survival?

2. What are some of the different characteristics of deciduous and evergreen trees? Why are some southern broadleaf trees described as persistent?

3. What observable changes occur seasonally to deciduous broadleaf trees? What adaptations do deciduous broadleaf trees have which enable them to survive prolonged periods of heat or cold?

4. What adaptations do evergreen trees have that enable them to survive prolonged periods of heat and cold?

5. What are the typical plant communities of the world? Why are specific kinds of plants limited to specific regions? What factors in the environment cause these limitations?

1. How can the stems of shrubs and the branches and trunks of trees survive through prolonged periods of heat and cold? Why do the aboveground stems of biennial and perennial herbs not survive? Why are the buds of trees and shrubs an adaptation for survival?

Find out whether the pupils know why *perennial* trees and shrubs can survive both higher and lower temperatures than the aboveground parts of biennial and perennial herbs. [The lignin (woody tissue) of trees and shrubs contains less water than herb tissue. The outer covering (bark) of trees and shrubs is thicker and less porous.]

Devise experiments to determine the amounts of water in the stems of herbs, trees, and shrubs. (One way this can be done is to compare the weight of stems which are approximately equal in length and circumference before and after they are dried.)

Remove some of the *bark* from stems and observe its thickness. Compare the thickness of the bark with the thickness of the outer membrane of herbs.

Observe the cambium layer under the bark of trees and shrubs. It is located between the bark and the woody tissues. The cambium is present in the main stems, tips of branches, and the leaf buds of trees and shrubs. Look for this layer in the stems of herbs. (It is lacking.) Find out the function of this layer. (The cambium tissues are the only tissues that can reproduce new cells after a plant has produced ripe seeds.) Why do the aboveground parts of herbs die after their seeds have matured? (They lack the cambium tissues necessary for continued growth.)

Take a field trip to examine the bark of trees and shrubs. Observe that each tree and shrub has a *characteristic kind of bark.* What causes the bark to crack and form ridges? (The bark is rigid; it splits when the cambium layer produces more cells.) How is the new bark formed? (The cambium tissues produce new bark annually.) Compare the thin bark *on branches* of different kinds of trees. Look for small openings called *lenticels.* Compare the arrangement of the lenticels on different kinds of trees. (For each species they will be characteristic.)

Encourage educated guesses regarding the reasons why the bark of different kinds of trees varies. (The weakest part of the bark, which is around the lenticels, splits as the circumference of the tree or shrub increases. Also, some trees, such as the fiddleleaf fig, the canoe or white birch, the eucalyptus, and the hickory, shed their bark annually. Some trees produce a thicker layer of bark than others and some trees grow faster than others. The texture and tensile strength of the tree's bark may differ.)

Select two trees of the same species but of different ages. Remove a small piece of bark from each. Examine the samples of bark with a magnifying glass. Compare their color, thickness, and texture.

Cut a twig from each of the trees. Note the arrangement of the leaf buds. Are they arranged *oppositely* from each other, *alternately* (leaf bud on one side slightly above leaf bud on the other side), or *spirally* (around the twig)? Are the leaf buds of the two specimens arranged in like or unlike patterns? (Like patterns.)

Compare the arrangement of the branches with the arrangement of the leaf buds. (They are the same.) Make similar comparisons using other species of younger and older trees. Results? (The leaf buds and branches of the same species will be arranged the same.)

Try to find trees whose leaves and branches are arranged oppositely, such as maples; alternately, such as oaks; and spirally, such as catalpas. Find out whether the arrangement of the dormant buds on the branches are the same for each species of tree. (They are. See Fig. 44.1.)

Make a collection of branches from different species of trees and study them in the classroom. Do the branches have dormant buds? (Yes.) Examine the outer covering of the buds. Classify them as conductors or insulators of heat. (Insulators.) Will the buds open if the branches are placed in water? (That depends upon the species and the proximity of the growing season. Most trees and shrubs which shed their leaves seasonally must have a dormant season before the buds will open.)

Why are dormant buds not killed at the end of the growing season? (They have better insulation than leaves have. They also have less surface and contain less water. *Dryness* is an important factor in survival during either very cold or very hot weather.)

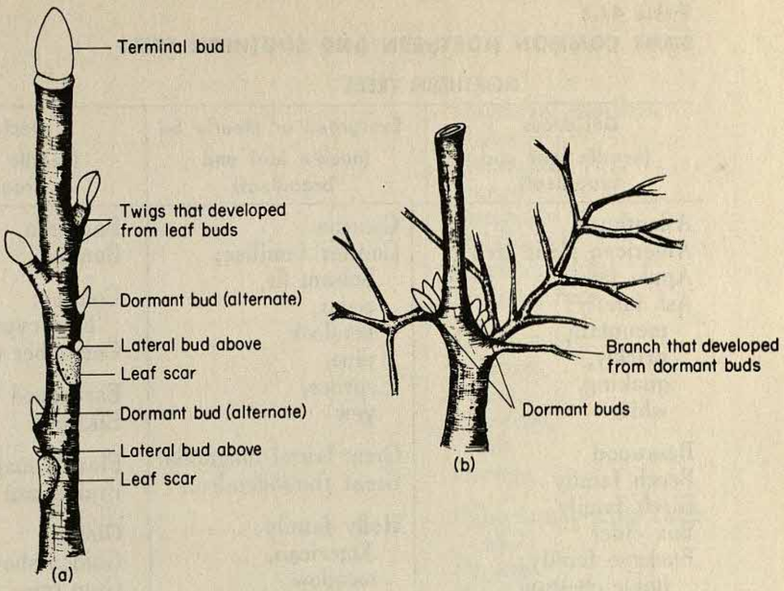


Fig. 44.1 Where buds form on trees and shrubs. (a) Dormant buds form well above the axil of the leaf of such trees as the honey locust, walnut, and butternut. (b) Two to four dormant buds form in the axil of such shrubs as the tartarian honeysuckle and the pipe vine (aristolochia).

When do buds form? The pupils should have the opportunity to make periodic observations of trees during the different seasons of the year. These observations will enable them to discover the time when buds form. (Buds form shortly after the leaves have matured. The time of year depends upon the climate.)

Discuss the following three questions. (1) Why is the lack of water in plant tissue an adaptation for survival? (When water in plant tissue freezes, it forms ice crystals that rupture or destroy the cells. The cells are literally torn apart.) (2) What effect does low temperature have on a plant's chemical processes? (The plant's chemical processes, which sustain life and growth, cannot continue when the temperature gets too low. For the chemical changes that are necessary to convert insoluble food into energy and building materials to take place, heat is needed.) (3) What are some of the special adaptations of evergreens? (As colder weather approaches, some evergreen *conifers,* such as pines, cedars, hemlocks, and spruce, produce *resins* that are suspended in the fluid in the cells of a tree's branches and trunk. These resins lower the freezing temperature of the tree's fluid to a point where only the severest cold will change it to ice. The presence of these chemicals in the water of plant cells is called *winter hardening.* Certain kinds of *broadleaf* evergreen trees, and shrubs also move water from the leaves into the branches before the temperature in the leaf tissues reaches the freezing point. Low temperatures are believed to stimulate such plants as the evergreen rhododendrons to move (translocate) water from the leaves to the stems. The reduction of water in the leaf tissues causes the leaves to curl inward and hang downward. If some of these rhododendron branches are brought into a warm room, the leaves will reopen and assume their normal position and condition or appearance.)

2. What are some of the different characteristics of deciduous and evergreen trees? Why are some southern broadleaf trees described as persistent?

List some of the differences in the characteristics of *deciduous and evergreen* (indeciduous) trees. Have the pupils use reference books to check the accuracy of their statements. (The leaves of deciduous trees live for less than one year and are shed *completely* during one season. Their branches are *bare* for a period of a few weeks to a few months. The leaves of an evergreen tree live *for more than one year* and are shed *gradually.* Their branches are *never bare.* Many broadleaf trees are deciduous but only a

Table 44.1

SOME COMMON NORTHERN AND SOUTHERN TREES

NORTHERN TREES

Deciduous (needle leaf and broadleaf)

- Ailanthus
- American plane tree
- Apple family
- Ash family;
  - mountain,
  - prickly,
  - quaking,
  - white

- Basswood
- Beech family
- Birch family
- Box elder
- Buckeye family;
  - horse chestnut,
  - yellow
- Burning bush
- Butternut
- Buttonwood

- Catalpa family
- Cherry family
- Chestnut family
- Conifer;
  - larch or
  - tamarack

- Ear-leaved magnolia
- Eastern redbud
- Elm family

- False acacia
- Fringe tree

- Ginkgo
- Gum tree

- Hawthorn family;
  - the haws
- Hop tree
- Hickory family
- Hornbeam family

- Judas tree

- Kentucky coffee tree

- Larch
- Large leaved cucumber tree
- Linden family

Evergreen or Nearly So (needle leaf and broadleaf)

- Cassena
- Conifer families;
  - balsam fir,
  - cedar,
  - hemlock,
  - pine,
  - spruce,
  - yew

- Great laurel magnolia
- Great rhododendron

- Holly family;
  - American,
  - meadow,
  - swamp

- Laurel, mountain

- Mountain laurel

- Rhododendron, great
- Rose bay

- Yaupon

SOUTHERN TREES

Deciduous (needle leaf and broadleaf)

- Bauhinia
- Bombax

- Conifer;
  - bald cypress
- Cucumber tree

- Ear-leaved magnolia
- Elkwood

- Florida maple
- Frangipani

- Ginkgo
- Golden shower tree
- Gum tree

- Hop tree

- Jacaranda
- Jerusalem thorn

- Kapok tree

- Large leaved cucumber tree
- Long leaved magnolia

- Mountain magnolia

- Orchid tree

- Parkinsonia
- Pecan
- Persimmon
- Plumeria
- Pomegranate
- Poinciana, royal

- Red gum

- Shaving brush tree

- Winterberry

Evergreen or Nearly So (needle leaf and broadleaf)

- Akee
- Albizzia
- Alligator apple
- Avocado

- Bahama lysiloma
- Banyan
- Barbados cherry
- Brazilian pepper tree
- Breadfruit

- Cajuput
- Cassena
- Ceylon gooseberry
- Christmas berry
- Conifer families;
  - balsam fir,
  - cedar,
  - cypress,
  - hemlock,
  - pine,
  - redwood,
  - sequoia,
  - spruce,
  - yew
- Coco-plum

- Dahoon
- Dombeya

- Earleaf acacia
- Eggfruit

- Ficus (fig)

- Geiger tree
- Great laurel magnolia
- Great rhododendron
- Grapefruit
- Guanabana
- Guava

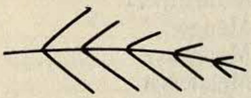
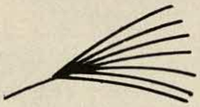
- Jambool

- Lemon
- Lime
- Live oak
- Loquat
- Longan
- Lychee

Locust; black, yellow Maidenhair tree Maple family Mountain magnolia Mulberry, red Oak family Osage orange Papaw Pear Pecan Persimmon Planer tree Plum Poplar Redbud Red gum Sassafras Sheepberry Smoke tree Sourwood Sumach Swamp magnolia Sweet bay Sweet gum Sycamore Tamarack Tupelo family; black gum, cotton gum, sour Tulip tree Umbrella tree Viburnum family Virgilia Wahoo Walnut family Wax myrtle Willow family Witch hazel family Yellow wood			Magnolia, southern Mahoe Manchineel Mango Mangrove Melaleuca Mexican apple Mexican rose Oak family; laurel, live, myrtle, silk Orange Palm family (See Table 44.2) Papaya Pond apple Punk tree Rose apple Rubber tree Sapodilla Sapote, white Schefflera Sea grape Sea hibiscus Soursop Southern magnolia Sugar apple Surinam cherry Sweet bay Sweet gum Swamp magnolia Tamarind Tecoma Wild tamarind Woman's tongue Yaupon

Note: Because trees are often known by more than one name, the same tree may be listed more than once.

Table 44.2
PALM TREES (TROPICAL AND SUBTROPICAL PERSISTENT BROADLEAF TREES)

Pinnate (feather shaped leaves)	Palmate (fan shaped leaves)
	
Acrocomia	
Areca	
Bamboo	Broad leaf lady
Bottle	
Cane	Cabbage
"Christmas"	Carolina
Coconut	Chinese fan
Cocos plumosa	
Date group	
Canary Island	
cliff	
India	
pigmy	
Senegal	
Feather	Florida silver
	Florida thatch
Gru-gru	
Jelly	
King	
Mac Arthur	Madeira
Manilla	
Phoenix	"Petticoat"
Pineapple	
Princess	
Queen	
Royal	
Solitaire	Saw cabbage
Sugar	Saw palmetto
	Swamp cabbage
	Washingtonia
Yellow butterfly	

few conifers such as tamarack or larch and the southern bald cypress are deciduous.

Most conifers (trees with either needlelike or scalelike leaves, which usually produce cones) and some species of broadleaf trees are evergreen. Most broadleaf trees that grow *in the north* are deciduous; a few are evergreen (rhododendron, laurel, holly, and some varieties of magnolia). There are many more broadleaf evergreen trees *in southern* than in northern regions.

Only a few kinds of broadleaf, deciduous trees grow in *the subtropics and tropics.* Some trees that grow in the south are called *half evergreen or persistent.* Half evergreen trees shed their leaves gradually throughout the year. These trees are never bare as are deciduous trees. In Table 44.1 any tree that is never bare is classified *as an evergreen.* Such trees as the tecoma, the various species of ficus, and the sea grape are classified as half evergreen.

3. What observable changes occur seasonally to deciduous broadleaf trees? What adaptations do deciduous broadleaf trees have which enable them to survive prolonged periods of heat or cold?

Select a *broadleaf, deciduous* tree which is located near the school and observe its changes throughout the year. List some of the changes that should occur to the selected tree during the year. (Some of these changes are: leaf color, leaf fall, new bud formation, new leaves, blossoms, formation and ripening of fruit, growth of trunk and branches in circumference and in length.)

Organize a table similar to 44.3 for recording observations. Discuss the reasons for classifying information in categories like those in Table 44.3. (Information can be recorded and located more rapidly. It makes it easier to see relationships and differences.)

Make several field trips with the whole class. Also make additional field trips with small groups to observe the selected tree. Discuss and record on the chart the observations resulting from these trips.

On a field trip during leaf fall, collect small branches and some of the leaves from the selected tree. Upon returning to the classroom, put the branches in water. Have class discussions regarding leaf fall as an adaptation that enables deciduous trees to survive long periods of heat, cold, and drought. Determine which kinds of trees—evergreen or deciduous—are more common in the local area. What are the climatic conditions when the trees in the area are bare? Which climatic conditions are most closely related to leaf fall? Encourage educated guesses. (Leaf fall occurs when *liquid* water is not available. In dry

Table 44.3

RECORD OF THE CHANGES OBSERVED IN A DECIDUOUS BROADLEAF TREE

Common name of tree__________ Scientific name__________
Date of first observation __________
Date of last observation __________

A. Trunk

1. Circumference of trunk when first observed. __________
2. Circumference of trunk when last observed. __________
3. Was there any change? If so, how much? __________
4. Color and texture of bark when first observed.__________
5. Record any change in color. __________
6. Describe any change in color and tell when it occurred. __________
7. List any other changes that were observed.__________

B. Branches

1. Circumference of branch No. 1 when first observed (nearest trunk).__________
2. Circumference of branch No. 1 when last observed.__________
3. Was there a change in circumference? If so, state the amount.__________
4. Length of branch No. 1 (from the trunk to the terminal bud) when first observed.
5. Length of branch No. 1 when last observed.__________
6. Was there a change in the length? If so, state the amount.__________
7. Color and texture of bark on branch No. 1 when first observed.__________
8. Record any change in color or texture of bark. __________
9. Describe any color or texture change in bark and tell when it occurred.__________
10. Circumference of branch No. 2 when first observed (nearest trunk).__________
11. Circumference of branch No. 2 when last observed.__________
12. Was there any change? If so, how much? __________
13. Length of branch No. 2 (from the trunk to the terminal bud) when first observed.
14. Length of branch No. 2 when last observed.__________
15. Was there a change in the length? If so, state the amount. __________

C. Twigs

1. Color of twigs on both branch No. 1 and No. 2 when first observed.__________
2. Color of twigs on both branch No. 1 and No. 2 when last observed. __________
3. If there was any color change during the year, state the time when it occurred.

D. Leaves

1. Are the leaves arranged alternately, spirally, or oppositely?__________
2. Describe the shape of the mature leaf. __________
3. Color of mature leaves.__________
4. Date when some of the leaves begin to show a change in color.__________
5. Date when most of the leaves have changed their color. __________
6. Date of the first killing frost.__________
7. Had any color change occurred in the leaves before the killing frost?
8. Did all the leaves change to the same color? If not, what colors were observed? (*There will be differences in the intensity of the predominant color. Several different colors may also be visible.*)
9. Why do all of the leaves appear to be the same color, when they are seen from a distance? (*There is more of one color than any of the others. Only the most abundant or predominant colors can be seen from a distance.*)

***Table 44.3* (*cont.*)**

10. What is the color of new leaves emerging from leaf buds? Compare the color with the color of a mature leaf and also with the predominant color of the leaves just before they are shed. (*The mature leaves are green. The predominant color of the leaves before they are shed and the newly emerging leaves is the same.*)

E. Blossoms and fruit

1. Date when blossoms were first seen.____________________
2. Did the leaves and blossoms develop from the same bud or from different buds?
____
3. Did the leaves and blossoms appear at the same time? When did they appear?
____
4. What is the color of the blossoms? ____________________
5. How are the blossoms pollinated? (*Showy blossoms such as fruit trees are pollinated by insects. Inconspicuous blossoms such as those produced by maples, oaks, and bald cypresses are usually wind pollinated.*)
6. Date when fruit (seed) matured.____________________
7. Describe fruit.____________________
8. By what method are the seeds dispersed? ____________________
9. Estimate the number of fruit on the tree in hundreds, thousands, or hundred thousands. (*Hundred thousands.*)

F. General problem

1. Estimate the age of the tree. (*Circumference when last observed divided by increase in circumference between first and last observation.*)

seasons or when temperatures are freezing or below, liquid water is not available. Both of these conditions are periods of drought.) Also discuss the causes for the change in the color of leaves before they fall. See Chap. 30 for information.

Observe the buds on the branches. Are the buds arranged alternately, oppositely, or spirally? Predict whether none, some, or all of the buds will develop into leaves. (None will develop if the branches are collected at the beginning of the dormant seasons.)

4. What adaptations do evergreen trees have which enable them to survive prolonged periods of heat and cold?

Encourage *predictions* regarding the answers to the questions in this inquiry. Past experiences should have developed the concepts that (1) transpiration is a function of leaves; (2) surface area is one important factor in the rate and amount of water that evaporates; (3) the outer membranes of trees and shrubs are less porous than the outer membranes of herbs; (4) the tissues of some kinds of plants contain less water than others. Use these four learnings to formulate hypotheses which state why conifers can survive drought conditions when broadleaf, deciduous trees can not. (1) The surface area of the leaves of conifers is less than the surface area of broadleaf tree leaves. (2) The leaves of conifers have less porous membranes than the leaves of broadleaf deciduous trees. (3) The leaves of conifers contain less water than the leaves of broadleaf, deciduous trees.

Plan and do experiments to find out whether the three hypotheses in activity number 1 are correct. The following is a sampling of the kind of experiments that can be done. (1) Obtain a branch from a conifer and another from a broadleaf, deciduous tree. Roll each of the branches in separate pieces of paper towels and close the ends of the rolls tightly. After several days have passed, check to find out which leaves have wilted and which ones feel drier. (2) Obtain equal amounts by weight of leaves from both a conifer and a broadleaf, deciduous tree. Place the leaves in separate glass containers and cover the jars tightly. The following day, observe the water droplets that have condensed on the inside walls of the jars. Which one has both more and larger droplets? (The jar containing the broadleaves.) (3) Remove the leaves from the jars and place them on separate pieces of paper towel. Fold the paper towel over the leaves. Put a piece of wax paper under each of the towels. Crush the leaves with a pestle or a hammer. Which kind of leaf made the larger water spot? (The broad leaves.) Which kind of leaves contained more oil? (The conifers.) (4) Obtain at least three or four grams of leaves from a conifer and three or four grams of leaves from a broadleaf deciduous tree. Place the two kinds of leaves on separate pieces of wax paper and crush them. Weigh separately the paper and the leaves from each kind of tree and record their weights. Expose the leaves to the air in the room for one week and then weigh them again. Which kind of leaves lost more weight? (The broad leaves.)

Summarize the results of the experiments and draw tentative conclusions. Why should the conclusions be tentative? (They are based upon only a few observations.) Discuss and summarize the data that have been collected during the study of the broadleaf, deciduous tree that the class selected. Help the pupils evaluate the experiences they have had during this study: What did they enjoy most? Which part of the study was most important? What changes would they recommend to another class that undertakes the study?

5. What are the typical plant communities of the world? Why are specific kinds of plants limited to specific regions? What factors in the environment cause these limitations?

Display large maps of North America and the world. On the map have the pupils locate places they have been. This discussion also could include the travels of family, friends, faculty, and local citizens. Locate the places where these people have been. Record the name of the place and its latitude. Find out whether the persons visiting these places have pictures that they can show to the class. Do these pictures show the plant communities of the areas? Also find out whether these travelers are willing to show the pictures and discuss the climate and kind of plant life they saw.

Appoint a committee to record this information and to help arrange for the visitors to participate in a class discussion. Because this inquiry is concerned with the worldwide distribution of plants, the decision as to whom to invite should be determined by the kind of plant community visited. Suggest that the committee consult the list of worldwide plant communities shown in Table 44.4, in order to arrange for discussions and pictures that represent as many different plant communities as possible.

Have the committee report their decisions to the class. Also discuss the type of local plant community and whether it contains natural or man-made plant communities.

Have the pupils find out what type of plant community existed in their region before it was developed by the first settlers. Discuss the types of plant communities your region and your state now support. Also discuss how important a factor man has been in changing the character of an area's plant community. Have the pupils describe the kinds of plant communities that are shown in some of their favorite television programs. Encourage guesses regarding the factors that limit the growth of specific plants to certain areas. (Some of these factors are latitude, altitude, amount of heat and light, availability of liquid water, soil nutrients, and the kind of soil.)

Compare the physical differences between a beach (barren land) and a nearby field (grassland). Some of the areas of difference are: (1) amount of heat and light reflected (water and sand reflect more heat and light than grass); (2) daily and seasonal variations in air temperature (there is less variation in temperature on a beach than on a field); (3) strength of wind (winds are likely to be stronger near water—this stronger circulation increases the rate of evaporation from the leaves of plants). Read, observe, and discuss some of the differences between the adaptations of plants that grow on a beach and those that grow in a grassland community. Some of them are as follows: (1) The outer membranes of the stems and leaves of many kinds of beach plants are thicker and less porous than those of grassland plants. (2) The stems of beach plants contain less water. (3) Beach plants have a widespread root system, which enables them to absorb water quickly. (4) Beach plants also have different mineral require-

Table 44.4

WORLDWIDE DISTRIBUTION OF GREEN PLANTS AND THE PHYSICAL AND CLIMATIC ENVIRONMENTS IN WHICH THEY LIVE

Green Plant Communities	Continents and Islands on Which They Grow	Latitude in Degrees North or South	Elevation Above Sea Level in Feet	Annual Rainfall in Inches	Climate in Brief	Summary of Climate and Physical Environment
Coniferous Forests, also called Boreal Forests, contain some birches, ashes, etc., mixed with the conifers.	Cover less than 10% of the earth. Grow mainly in the northern part of Europe, Asia, and North America.	50–70 north	0–1000	20	Climate is subarctic. Winters are either cold and wet or cold and dry. Summers are short and cool.	Grow in lowlands that are less than 1000 feet above sea level. Summers are short and cool. Winters are long and cold.
Broadleaf Evergreen Forests, also called Rain Forests and Jungles, contain abaca, balsa, cassava, cocoa, mahogany, rubber, sago, and teak.	Grow on every continent with the exception of North America and Europe. Also grow on every major island with the exception of those in the high latitudes.	0–25 north and 0–40 south	less than 1000	50–80	Climate is tropical. Sufficient rainfall every month to support abundant plant life. Temperature variation from one day to the next is not more than 5 degrees.	Grow in tropical lowlands where the rainfall is abundant throughout the year. Little daily variation in temperature.
Broadleaf Deciduous Forests contain oaks, maples, elms, and ashes. Shed leaves during dry seasons.	Grow on every continent and on the island of Madagascar.	5–60 north and 5–40 south	0–1000	40–60	Climate is damp or rainy. There is either a dry or cold season when trees are bare and dormant.	Extend from the borders of the subarctic to the tropics. Grow in either damp cool or warm wet temperate climates.
Mixed Forests consist of conifers, and broadleaf deciduous trees. Both are valuable for timber.	Grow in eastern North America, central Europe, and eastern Asia.	30–60 north	0–2000	10–40	The climate is subarctic with enough rain or snow in all months to prevent drought conditions. If there is a dry season, it occurs	Located where summers are short and cool; winters, long and cold. No drought conditions because precipitation is ade-

					during the months when the deciduous trees are bare. These trees grow where the average monthly temperature is 50 degrees Fahrenheit for at least four months.	quate during the months when growth occurs.
Shrub lands, also called Bush Country and Scrub Country.	Grow on all continents and the islands of Indonesia and Madagascar.	0–50 north and 0–50 south	0–10,000	0–10, in higher latitudes as much as 10–20	Most are located in semiarid, tropical regions. Some, in the high latitudes of both the northern and southern hemispheres where winters are cold and dry and summers hot and dry.	Located mainly in semiarid tropical highlands. Some located in arid tropical lowlands. Some in the high latitudes of the temperate zones.
Grasslands, also called Prairies, Savannahs, Park lands, and Steppes.	Grow on all continents and major islands in the temperate zones and in the tropics.	0–55 north and 0–35 south	0–3000	20–40	In *subarctic* where summers are cool and short; winters, long, cold, and wet. In *middle latitudes* where summers are short and hot; winters, cold and wet. In the *tropics* where the summers are warm and rainy; winters, dry.	Located where rain fall is moderate. Climate varies from subarctic cool to rainy temperate, to dry winter tropics.
Barren lands, also called Icecaps, Frozen lands, Tundras, High Mountains, and Deserts.	Located on every continent of the world.	0–90 north and south	0-more than 10,000	10 or less	In climates that are arid, arctic, subarctic, temperate, or tropical.	Located where rainfall is usually less than 10 inches a year, and where there is ice cover or frozen land.

ments than grassland plants. Use a similar discussion to compare other types of plant communities, such as deserts and prairies, brush lands and deciduous forests. These discussions should develop the concept that one kind of environment differs from another mainly in the amount and availability of sunlight, liquid water, and minerals in the soil. Deduce some of the probable changes that would occur in a plant community if the environmental factors listed in the previous paragraph were to change. For example, if a hot, dry desert received the amount of water that falls in a rain forest, what would happen to the desert? What effect does the amount of rainfall have on the kinds of mineral nutrients present in the soil? [The presence of most mineral nutrients is determined by the kinds of living things, by the rate at which living things decompose, and by leaching (washing out of mineral nutrients.)] A change in the amount of rainfall will change also the amounts and kinds of minerals that are present in the soil.

Read, observe, and discuss the kinds of adaptations that enable some kinds of plants to thrive in intense sunlight. [The outer membranes of the stems and leaves of "sun-loving" plants may be leathery, coated with wax and resin, or they may be covered with hair (down). The leaves of some kinds of plants that thrive in intense sunlight have a reduced surface area; others are shaped to expose a minimum amount of surface. Both adaptations reduce the amount of light and heat a leaf can absorb and the amount of water it can lose by evaporation.]

Read, observe, and discuss the adaptations that enable some kinds of plants to hold water for long periods of time. (Some of the most interesting adaptations are those that are found in desert plants. Cactuses have widespread root systems, which enable them to absorb large amounts of water quickly, when it occasionally becomes available. The water stored in the trunk of the plants can be used during drought periods. Desert plants have either leathery leaves or leaves reduced in size until they are just thorns. A saguaro cactus may weigh as much as ten tons, but 80 per cent of this weight will be water. Its trunk and spines expose the minimum amount of surface from which water can evaporate. Its thousands of bristling spines also discourage its destruction by thirsty animals.)

Read, observe, and discuss why some plants can survive long periods of drought, even when they lack the adaptations for holding water. (There are many places besides deserts where it is difficult for plants to get water. For example, the tundras of the north have plenty of water, but for most of the year it is in the form of ice and snow, which plants cannot use. The tundras have many small plants that burst forth in bloom shortly after the ice and snow begin to melt. Deserts also have many small plants that bloom shortly after a cloudburst. These small plants do not have specialized storage places for water, but their species continues to survive because they have a *very short* reproductive life cycle. The plants go through the cycle from seed to mature plant and back to seed again in a very few weeks. The seeds survive the drought period of desert and tundra and germinate when water is again available.)

Experiences similar to the following will help to broaden the pupils' understanding of and appreciation of the effects of climate and physical environment on the distribution of plants in various regions of the world.

Plan and take a field trip to observe different kinds of plant communities. In many regions, several different kinds are located only a short distance from the school. For example, city children can visit a botanical garden or a park where different plant communities are growing. Pupils who live in suburbs and rural regions often have several natural plant communities growing within a few minutes walking distance from their school.

World atlases and wall maps can be used to provide additional experiences that will enlarge the pupils' understanding of the relationships that exist between land types and the distribution of green plants. Arrange several supervised study periods in which the pupils can use maps to locate the regions in which the major types of green plant communities grow. See Table 44.4 for the major types of plant communities.

From their studies, have the pupils draw tentative conclusions regarding the two major factors that control or restrict the distribution of different kinds of green plants on the earth. (The two major factors that control the distribution of different plant communities on the earth are the amount of sunlight and the amount and availability of liquid water.)

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Trees and shrubs have several adaptations that enable them to survive unfavorable weather conditions. The parts of trees and shrubs that grow above the ground are covered with bark. Bark is a better insulator than the outer covering of the stems of herbs. The stems of trees and shrubs are composed of lignin, which contains less water than the fleshy stems of herbs. The stems of trees and shrubs have a thin layer of tissue called cambium. The cambium contains the only plant cells that can reproduce new cells after the plant has matured. The stems of herbs lack the cambium tissues that make it possible for the stems of trees and shrubs to grow year after year.

The buds of trees and shrubs are better insulated than the buds of herbs. The time of year in which buds are formed on trees and shrubs depends upon the climatic conditions in the regions in which they grow. Dormant buds are also adaptations that enable trees and shrubs to survive unfavorable weather conditions.

2. In most regions of the world, there are broadleaf deciduous trees that undergo seasonal changes. A deciduous tree sheds all of its leaves during one season of the year and is without leaves for a period that varies from a few weeks to several months. An evergreen tree retains the same leaves for a period of at least two years.

Some trees are described as having green leaves that are persistent throughout the year. A tree that has persistent green leaves sheds its annual crop of leaves gradually throughout the year. As the persistent green leaf tree sheds its leaves, they are replaced by new ones.

An evergreen tree sheds its two-year-old leaves gradually through the year. Evergreen trees also develop new leaves as the old ones are shed.

3. Leaf fall is an adaptation that enables broadleaf deciduous trees to survive seasons in which liquid water is not available. The buds of deciduous trees do not develop until they have passed through a dormant period.

Most broadleaf deciduous trees grow in northern climates. Most broadleaf evergreen trees grow in southern climates.

Broadleaf deciduous trees that have survived in regions in which there are seasons in which water is scarce usually shed their leaves before the arrival of drought conditions. Drought conditions can be caused either by freezing temperatures or by very hot dry weather.

4. Conifers and some kinds of broadleaf evergreen trees can survive drought conditions without shedding their leaves because they have adaptations that enable them to conserve water. The leaves of most evergreen trees contain less water than the leaves of broadleaf deciduous trees. The reduction in the surface area of the leaves of conifers reduces the amount of water that is lost by evaporation through the leaves. The leaves of evergreen trees have outer membranes that are less porous than the softer membranes of the leaves of most broadleaf deciduous trees.

5. Green plants are limited by their adaptations to a certain kind of environment. One kind of environment differs from another mainly in the amount of sunlight, available liquid water, and the minerals that are obtained from the soil.

Changes in the amount of sunlight and the amount of available liquid water in an environment would also cause changes in the minerals that are present in the soil. Most of the minerals in the soil are obtained from the decomposition of living things. The kinds and amounts of minerals present in the soil are determined by the kind and abundance of living things, the rate at which they decompose, and the leaching that occurs.

Plants that survive in different regions on the earth have adaptations that enable them to obtain the sunlight, liquid water, and the minerals they need to grow and reproduce. The adaptations that plants have that result in survival vary from one kind of an environment to another. The major factors that control the distribution of plant communities on the earth are the amount of sunlight and the amount of available water.

Chapter Forty-Five

Seed Adaptations for Surviving Seasonal Changes

INQUIRIES

1. What one method of reproduction is common to all flowering plants? What other methods of reproduction do flowering plants have?

2. Why is seed production, survival, and germination important to the continued existence of flowering plants?

3. Why are both the number and the size of the seeds produced important factors to the survival of flowering plants?

4. Why are some of the seeds grown in your region unable to survive the dormant season? Why can many kinds of seeds that grow in your region survive the dormant season?

5. Why do mature dry seeds have a better chance of surviving dormant seasons than mature wet seeds? How does the outer membrane of a seed help to keep it dry?

6. What classes of foods are stored in different kinds of seeds? What effects do these foods have on seed survival?

7. What are some of the adaptations that enable some seeds to survive dormant seasons?

1. What one method of reproduction is common to all flowering plants? What other methods of reproduction do flowering plants have?

Chapters 42, 43, and 44 developed a number of concepts that should be applied to the solution of this problem. Encourage the pupils to recall the following experiences which they can apply to this inquiry.

1. Flowering plants produce seeds. Flowering plants are also called seed-bearing plants.
2. Seeds produce new flowering plants like the parent plants.
3. Seed production is *a method of reproduction common to all seed-bearing plants.*
4. *Herbs* (annual, biennial, and perennial), *trees,* and *shrubs* are seed-bearing plants.
5. Some seed-bearing plants *can reproduce only from seed. (Annual herbs* are grown each year from seed. *Biennial herbs,* such as carrots, turnips, and parsnips, are also grown each year from seed.)
6. Some seed-bearing plants have *other methods of reproduction in addition to the common method of reproduction from seed.* [Biennial bulbs, corms, and tubers can be reproduced from new bulblets, corms, and tubers. Perennial chrysanthemums, begonias, African violets, coleuses, geraniums, cathedral bells, and so on, and many kinds of perennial trees and shrubs can be reproduced from new underground stems, from cuttings (slips), and from leaves.]

2. Why is seed production, survival, and germination important to the continued existence of flowering plants?

Review the seven plant communities in Table 44.4 Discuss why seed production, seed survival, and seed germination are important to the continued existence of these communities. Questions similar to the following ones could be used.

1. If the physical environment and the climate remain unchanged, how can plant communities, which are lost by fire, wind, flood, and so on, be renewed?
2. What may happen to a plant community, if the physical environment and the climate that support it should change?
3. What theories help to explain why some prehistoric plant communities became extinct?
4. Why is a basic plant community apt to change when man settles in it?

A discussion of the previous questions should lead to the conclusion that, as long as conditions favorable for growth remain unchanged, generation after generation of the same kinds of seed-bearing plants may continue to grow in the same region. The survival of these plants depends on: (1) the ability of the plants to produce seeds, (2) the ability of the seeds from these plants to survive, and (3) the ability of these seeds to germinate and grow into healthy seedlings.

Discuss how foresters have applied the knowledge of seed production and survival to promote good forest management. (More and more frequently when forests are harvested, some healthy seed-bearing trees are left uncut. The seeds from these trees will reseed the cut over area. Sometimes cut over forest areas are reforested by seeds dropped from airplanes. Seeds for reforestation are often harvested from certain trees that have desirable characteristics such as greater resistance to disease and more rapid growth. These seeds are selected to improve the quality of the new forest. Both seeds and seedlings are used in reforestation. Governments are urging farmers to start tree farms on land that is not being used for pasture or for growing crops. Commonly these government agencies supply tree seedlings free to cooperating farmers.)

3. Why are both the number and the size of the seeds produced important factors to the survival of flowering plants?

Have the pupils make a collection of seed pods, blossom heads, and fruits. In this collection, try to include seeds that vary in size from very small to very large. (This collection could vary from the large size of the coconut to the dust-size seed of many kinds of orchids and of many weeds.)

Have the pupils count and estimate the number of seeds in each (1) seed pod, (2) blossom head, and (3) fruit. Where the count involves a large number of seeds, the pupils can devise ways to count part of the seeds and estimate the whole number of seeds from this partial count.

Where possible, count the number of seed pods, blossom heads, or fruit produced by one plant. Use this count, together with the estimated number of seeds in one pod, blossom, or fruit, to determine the possible number of seeds produced by the plant. To determine the average number of fruit, blossoms, or seed pods produced by some plants, the pupils may need to consult gardeners, farmers, foresters, and seed companies.

Also have the pupils devise a way to grade seed size, by using code numbers. For example, extremely large seeds (coconut) could be code number *1*. Very large seeds, such as an avocado, mango, or peach, could be code number *2*. Large seeds, such as bean, corn, squash, and pea could be coded *3*. Small seeds, such as radish, beet, and tomato, could be numbered *4*, and very small seeds such as poppy, petunia, orchid, and weed, could be numbered *5*.

Have the pupils set up a three column table titled "Seed Production." In the first column, list the names of the seeds which the pupils have examined. In column two, record the code number that indicates the sizes of the seeds, and in column three, note or record the estimated total number of seeds produced by each plant.

Consult the table to find out if there is a correlation between seed size and seed production. (There seems to be an inverse relationship. Larger seeds are produced in smaller quantities, smaller seeds in larger quantities.) What implications can be drawn from this inverse relationship? (1) Plants that produce small quantities of large seeds and plants that produce large quantities of small seeds continue to survive in a community if the conditions for their germination and growth are favorable. (2) The size of seeds seems to be an important factor in their survival. (3) The number of seeds produced by certain kinds of plants seems also to be a factor.

What implications can be deduced from the relationship that seems to exist between the size of seeds, the number produced, and their survival in a plant community? *Speculate* regarding what would happen if a coconut, a walnut, or butternut tree produced as many seeds as a maple, an elm, or such plants as milkweed and goldenrod. What happens to large seeds when they are ripe? (Some of them are carried off or eaten by animals; others remain on the ground where they fall.) These large seeds on the ground would be stacked in thick piles beneath the parent plant. In such thick layers, most of the nuts would mold, decay, or be destroyed by unfavorable climatic conditions. Few, if any, of these seeds would germinate and develop into healthy plants. The seeds which do germinate and grow into healthy plants would have to fall, roll, float, or be carried by man or animals to a favorable environment. For this reason, it seems that large seed size combined with small seed production is an important adaptation enabling plants to survive.

Flowering plants that produce thousands and millions of small seeds also continue to survive in their natural plant community. Small seeds that drop to the ground under the parent plant have a better chance of survival because they will not be piled in such thick stacks. These tiny seeds probably would not be destroyed by mold, decay, and climatic conditions. Small seeds do not use as much room in which to grow as do large seeds. Also small seeds may have adaptations that enable them to be carried away from the parent plants. Some are carried by wind (maples, elms, basswoods, willows, milkweeds, cattails, and so on). Some small seeds are accidentally carried away by animals (burdocks, sandburs, beggar-ticks, and so on). The fruits of some kinds of plants are eaten by animals (raspberries, blueberries, strawberries, cherries, and so on). The small seeds contained in these fruits pass undamaged through the animals' intestines and may fall on the soil in places that are favorable for their growth. For these reasons, it seems that small seed size, combined with large seed production, is also an important adaptation resulting in survival.)

4. Why are some of the seeds grown in your region unable to survive the dormant season? Why can many kinds of seeds that grow in your region survive the dormant season?

Discuss why farmers always harvest, protectively store, and replant some kinds of seeds. From this discussion, some of the following ideas should evolve. (Seeds have been carried by wind, water, animals, and man from one region to another. *If these imported seeds can survive the region's dormant season, they will develop plants that will reseed themselves year after year.* Petunias, cosmos, annual pansies, sunflowers, and many kinds of poppies reseed themselves in adopted environments. *If the imported seeds cannot survive the dormant season, they must be harvested, protectively stored, and replanted by man.* Some gardeners harvest and save seed from their own plants; but more often the seeds are purchased from seed stores and companies at the beginning of the growing season. When the life cycle from seed to seed is longer than the growing season, seedlings are planted rather than seeds (tomato, cabbage, tobacco, rice, and so on).

Have the pupils list some of the plants that reseed themselves year after year. Check the list to find out whether the plants are *native to the region* or have been *introduced into the region.* (Most of the plants on the list will be native plants.) Also check the list of plants to determine whether they are cultivated or uncultivated. Should the children list such cultivated plants as clover, vetch, timothy, and certain kinds of lawn grass, remind them that these plants are *perennials* and are not reseeding themselves. These plants develop from rootstalks, which remain alive during the dormant season. Observe that most of the plants on the list are uncultivated plants.

5. Why do mature dry seeds have a better chance of surviving dormant seasons than mature wet seeds? How does the outer membrane of a seed help to keep it dry?

Help the pupils collect seeds from the various annuals that grow in the community. Because they are usually easy to obtain beans, peas, corn, cereal grains, and the mature seeds from pumpkins, squashes, sunflowers, and watermelons are good choices. Soak part of the seeds overnight. The next day compare them with the unsoaked ones. (The dry seeds will feel harder. The wet seeds will feel softer and the membrane will be easy to remove from some of them.)

Ask the pupils to guess whether dry or wet seeds are more likely to survive dormant seasons. Ask them to state also any reasonable evidence to support their assumptions. Some of the pupils may have noticed, when they were shucking green peas, that some of the larger peas have germinated inside the pod. Occasionally, they may have found seeds that have germinated inside very ripe oranges and grapefruits. *When such wet seeds germinate just before a dormant season, the tiny plants usually are not able to survive.* When favorable amounts of heat and moisture are present in the soil, *dry seeds also may germinate too early.* If this happens, the young plants will not be able to survive the hot dry or cold dry climatic conditions that follow. Wet seeds are much more likely to mold and rot than dry seeds. Farmers try to harvest their seeds when they are ripe (mature) and dry. If a rain occurs during the harvest season, many of the seeds will not survive, even when they are placed in a shelter in which the temperature is controlled.

Will dry seeds survive extremes in temperature better than wet ones? This experience is used to explore and compare the ability of seeds to survive temperatures which are below 32°F. Prepare the seeds in these four ways: (1) a *whole seed,* (2) a *seed without its outer coat,* (3) a *seed opened to expose the embryo,* and (4) an *embryo complete and severed from the rest of the seed.*

Divide the class into three groups. Assuming lima bean, black-eyed pea, and sunflower seeds are to be used, give one group lima bean seeds; one, black-eyed pea seeds, and another, sunflower seeds. Each group should soak thirty or more of their kind of seeds overnight to simulate seeds going into the dormant season in a wet condition. Have each group follow these directions for preparing and wrapping the dry seeds.

1. Wrap five whole dry seeds in a dry paper towel.
2. Remove the outer seed coat or membrane from five dry seeds. Wrap in separate dry paper towels.
3. Open five dry seeds to expose an undamaged embryo. Wrap in separate paper towels.
4. Carefully remove the embryo from five dry seeds. Make sure these embryos are undamaged. Wrap in towels.
5. Get a plastic food bag and a paper grocery bag. Have each group put its packages of prepared dry seeds in a plastic food bag. Tightly twist the top of this bag and place it in the grocery bag.

Using the soaked seeds, have the same three groups repeat the directions given above for dry seeds. Before preparing or wrapping the seeds, blot them with towels until no water remains on the surface. Then prepare and wrap them in fresh dry towels.

Have each group label its two grocery bags. Put all bags in a freezer for 48 hours. Check the temperature inside the freezer. (It should be below 0°F.) On the day the pairs of bags are removed from the freezer, open the seed packages. Observe whether there are any visible signs of growth. (There will be none.) Rewrap and sprinkle each paper towel package. Return the seeds to their original bags. Place in a warm place. Every day open, observe, and record any evidence of embryo growth. What can be observed? (The seeds that were frozen after being soaked overnight did not germinate. The embryos in the whole dry seeds germinated. The embryos in the dry seeds without their outer membranes germinated. The embryos exposed by opening the seeds germinated. *The embryos severed from the seeds also began to grow. They increased considerably in size.*) What tentative conclusions can be made? (Seeds which remain dry can survive freezing temperatures better than seeds which have absorbed water. A dry embryo can germinate after it has been frozen. Dryness may be a factor which increases a seed's ability to survive freezing temperatures.)

Some pupils may wish to repeat the four seed preparations in the previous experiment to explore the ability of wet and dry seeds to survive temperatures above 100°F.

Encourage the pupils to devise experiments to find out whether or not all or any part of a seed's outer membrane is porous. One way to discover this is to put mature dry seeds in water and observe them closely. After several minutes, air bubbles will form on the seeds. What causes these bubbles? Will such things as marbles or other nonporous objects also cause air bubbles to form? Try putting them in water too. (Bubbles will form for a few seconds after they are dripped into the water. This is caused by a small quantity of air clinging to the surface of the nonporous objects.) Note that bubbles continue to form on the seeds for 30 minutes or longer. Where do these bubbles originate? (From the inside of the seeds.) What tentative conclusion can be drawn? (A mature dry seed contains air. Either all or a part of the outer membrane may be porous because air escapes through it. Either all or a part of the outer membrane is not waterproof because water enters the seed.)

Continue to soak the seeds overnight. The following day remove the seed coats. The seed coat of popcorn may be removed by pinching off the point of the seed with the thumbnail and index finger. Then tear the membrane off in strips. Black-eyed pea and lima bean membranes split along the ridge of the seed. This ridge is opposite from the place where the seed was attached to the pod (the *hilum* or *eye*) of the seed. The sunflower seed splits at the pointed end, called the *hilum*. The seed coat of the corn does not split open until the embryo pushes its way through the hilum. (See Fig. 43.1) Where are the most likely places for air to escape and for water to enter these seeds? (There are two places. One place is where the membrane splits along the ridge. Another place is through the hilum. In addition to being the place where the seed is attached to the parent plant, in the center of the hilum there is a hole. This hole was made by the pollen tube when the seed was fertilized. (See Chapter 14, Inquiry 3.)

What other experiment can be done to find out if all or most of the membrane of a seed is airtight? Try this experiment and any others that the pupils can devise. Will the seed coats from lima beans and black-eyed peas float? (They will float if the membranes are reformed into their original shape. The seed coats will look like air bladders floating on the water. Most of the "boat-shaped" halves of the sunflower seed coats will float, and all of the corn seed coats will float.) Leave the seed coats floating overnight and in the morning observe what has happened to them. (Most of them will still be floating.) The results of this experiment provide an indication that most of the surface of the seed coat is impervious to water.

6. What classes of foods are stored in different kinds of seeds? What effects do these foods have on seed survival?

In water soak overnight at least 140 sunflower seeds, 120 corn seeds, 50 black-eyed peas, and 15 lima beans. In Chap. 43, Inquiry 1 see the directions for removing the seed coats. Keep the different seed meats (cotyledons) and their seed coats in separate containers of water until they are used. Crush the seed meats. A mortar and pestle are the easiest utensils to use. A mixing bowl with a wooden potato masher or with a wooden mallet also may be used. Grind each kind of seed meat into very fine pieces. Note that there is a small amount of a white powdery substance in the crushed meats of black-eyed peas, lima beans, and corn. None can be seen in the crushed sunflower meats. This white substance will be identified when the seed meats are tested. For each of the following food tests use equal small amounts by weight. To weigh put a piece of plastic food wrap on the plate of a gram scale. Always use this same piece of plastic. Be sure to clean it before using it again.

Test for Fat. Place the weighed samples of crushed seed meats on separate pieces of *unglazed brown paper*. Press the pestle or hammer firmly against each of the crushed seed-meats.

Examine the pieces of brown paper. (The black-eyed pea, the lima bean, and the sunflower seed meats left grease spots on the brown paper. The raw popcorn seed meats did not make a grease spot.) Observe and record on a table similar to Table 45.1 whether the seed meats contain much fat, some fat, or no fat. Why do raw popcorn seed meats not cause grease spots?

Encourage the pupils to devise experiments that may detect the presence of oil in popcorn. (They may devise simple experiments. Mix some water with the crushed meats and see whether the mixture will leave grease spots on brown paper. (They will not.) Add water and cook the seed meats. Repeat the test. (Fat will be observed on the brown paper.)

Test for Starch. Weigh equal small portions of the crushed seed meats. Lay these portions on separate pieces of food wrap. Use either cornstarch or laundry starch as a control. Place a drop of iodine solution on the cornstarch or laundry starch. Observe that the iodine changes to a dark blue color when it contacts the starch. If a substance contains starch, it will change iodine to this color. Now test the samples of crushed seed meats with iodine to find out whether they contain starch or not. (The black-eyed peas, lima beans, and corn will change the color of the iodine to dark blue. The tests are positive—the seeds contain starch. The sunflower seeds will not change the color of the iodine. This test is negative.) Record the results of the test on a chart similar to the one in Table 45.2. Next, test the *membranes* of each of the different kinds of seeds and record the results. Open several of the soaked seeds that were saved for additional testing and find out if the *embryo* contains starch. (There is no change of color observed in these tests.) Emphasize that a negative test does not confirm the absence of starch. It may only mean that the amount was too small to be measured by this test. This qualification should also be used in all tests that are made. Finally, test the white powder present in crushed black-eyed peas, lima beans, and popcorn for starch. Record the result. (The result is positive.)

Test for Single Sugar. Use equal small amounts by weight of each of the crushed seed meats. Place the seed meats in separate test tubes. Into the tube, pour equal amounts of water to moisten the seed meats. Mix well. In a drugstore buy a roll of Tes-Tape. Tes-Tape is a roll of chemically treated paper tape which is used to test urine for the presence of a single sugar. Use 1½-inch pieces of this tape to find out whether single sugar is present in the raw seed meats. Follow directions and symbols given on the Tes-Tape for interpreting the results of the tests. Use these symbols to record the results on a table similar to Table 45.3. Observe in Table 45.3 that there is a column to which you may attach the used strips of Tes-Tape. Also note that, before the tapes are fastened, this column should be covered with a piece of plastic food wrap. The waterproof food wrap makes it possible to add a drop of water again and again to each of the tapes. By wetting the tape the original color change can be observed over and over, without materially changing the results of the test. As a control use such juices as orange, pineapple, apple, and cranberry to show that the Tes-Tape reacts to the presence of *single fruit sugars*. Use table

Table 45.1

RESULTS OF THE FAT TEST

Quantities: XX = much, X = some, O = no evidence

Name of Raw Seed Meat	Quantity
Black-eyed pea	X
Lima bean	X
Popcorn	O
Sunflower	XX

Table 45.2

RESULTS OF THE STARCH TEST

Quantities: XX = much, X = some, 0 = no evidence

Name of Raw Seed Meat	Quantity in Seed Meat	Quantity in Outer Membrane	Quantity in Embryo	Quantity in White Powder
Black-eyed pea	XX	X	0	XX
Lima bean	XX	X	0	XX
Popcorn	XX	X	0	XX
Sunflower	0	0	0	No white powder to test

Table 45.3

RESULTS OF THE SUGAR TEST

Color code symbols from Tes-Tape container: + = some, 0 = no evidence
Quantity code: XX = much, X = some, 0 = no evidence

Name of Raw Seed Meat	Mount Tes-Tape here over Plastic Wrap	Color Code Symbol	Quantity Code Symbol
Black-eyed pea		0	0
Lima bean		0	0
Popcorn		+	X
Sunflower		0	0

sugar (double sugar) to show that the test does not react to double sugars.

Test for Proteins. Burning is a very simple test for proteins. Use forceps to hold some *whole seed meats* in the flame of a lighted candle. Compare the odor of the burned seed meats with the odor of such burned proteins as meat, hair, and burned starches (crackers, bread). Give each pupil the opportunity to make this test and to record his results on a chart similar to the one in Table 45.4. Some children may want to burn some seed embryos to find out whether they contain protein. If they wish to do so, use embryos that have been growing for several days. When embryos are several days old, they are easier to handle than the tiny dormant embryos.

During the discussion of the results, find if the pupils know *why small amounts of protein must be present even though it was not detected by the burning test.* (The burning test for protein does not always produce a strong enough odor to be detected. The acid test can detect smaller amounts of protein.) Use forceps to put the food sample into a test tube. Add a few drops of concentrated nitric acid. Heat the tube gently over a flame. Remove the test tube from the flame and let it cool. Rinse the food sample with water (two or three times) and then add a few drops of ammonium hydroxide. (If protein is present in the food, there will be a color change to deep orange. This test is recommended for older pupils under the supervision of a teacher. The protoplasm in the cells of all living things is composed of proteins. The plant embryos were not removed before the seed meats were ground. The tissues in the embryo are composed of proteins. There also may be some protein in the stored food.)

Summarize the results of the food tests. Make a summary table similar to Table 45.5.

Some of the following experiments will help the pupils to discover what effects the food stored

Table 45.4

RESULTS OF THE PROTEIN TEST

Quantities: XX = much, X = some, 0 = no evidence

Name of Raw Seed Meat	Quantity in Seed Meat	Quantity in Embryo
Black-eyed pea	X	XX
Lima bean	X	XX
Popcorn	X	XX
Sunflower	XX	XX

Table 45.5

SUMMARY OF THE FOUR CLASSES OF STORED FOODS IN A FEW KINDS OF SEED MEATS

Quantities: XX = much, X = some, O = no evidence

Name of Raw Seed Meat	Test for Fat	Test for Starch	Test for Single Sugar	Test for Protein
Black-eyed pea	X	XX	O	X
Lima bean	X	XX	O	X
Popcorn	O	XX	X	X
Sunflower	XX	O	O	XX

in the seed has on survival. Obtain a one-piece plastic ice cube tray and a metal pan in which to set it. Plastic drinking cups also may be used for this experiment. Place the same amount by weight of crushed black-eyed pea, lima bean, popcorn, and sunflower seed meats in separate sections of the plastic ice cube tray. In a fifth section of the tray, place an amount of water equal to that of the crushed seeds. This water is used as a control. Make a label from masking tape and use an ink marker to write an identifying symbol for each material in the tray. (For example: 1 = black-eyed peas, 2 = lima beans, and so on.)

Place the plastic tray on the metal pan. Put them in the freezing compartment of the refrigerator. Make observations at 30-minute intervals. (In 30 minutes, ice crystals will have begun to form on the water. No ice crystals will be seen on the other substances. Between one and one-half and two hours, all substances in the cubicles will be frozen.)

In order to test for the amount of ice present in each of the other substances, probe with the point of a paring knife. When the knife does not penetrate any of the substances, remove the tray from the refrigerator. Let it stand for at least five minutes. Then, try to loosen the frozen cubes from the walls of the tray. (A table knife is a good tool to use for this purpose.)

As soon as each cube can be removed, place it in a separate container. Observe the order in which the cubes can be loosened from the plastic ice cube tray. [The order in which they can be loosened will be the same as the order in which they will melt. The order is: (1) water, (2) black-eyed peas and lima beans, (3) sunflower seeds, and (4) popcorn.] The frozen cubes of black-eyed pea, lima bean, and sunflower seed meats will probably retain their cubical shape after they melt. Therefore it will be necessary to probe them with the point of a paring knife and to listen for the crackling sound of ice in order to know when they are completely melted. The crushed corn seed meats will not freeze because when these seeds were soaked, they absorbed very little water. In the crushing process, most of this water evaporated. Some children may want to repeat this experiment several times to find out if the same results will be obtained each time.

Analyze and summarize the results of the experiment. (Seed meats are poorer conductors of heat than water. Corn seed meats seem to be even poorer conductors of heat than the other three kinds of seed meats.) Challenge this last statement, and have the pupils locate tables in reference books, which contain the percentages of carbohydrates, proteins, and fats in these foods. Compare the percentages of fat, protein, starch, and sugar in each. (These tables can be found in books on nutrition and in elementary chemistry books. Also see Table 13.1.) Finally, consult the summary table the pupils made earlier. [The tables that have been suggested will show that corn contains more carbohydrates and fats than black-eyed peas and lima beans. Sunflower seed meats contain large amounts of fat and some protein. Both sunflower seeds and corn contain edible oils (fats in a liquid form). It is also possible that edible oils and proteins may be poorer conductors of heat than carbohydrates.]

Many pupils who live in regions where ice forms on pavements know that a salt is used to melt this ice. This salt is *calcium* chloride, not *sodium* chloride (table salt). Children who have made ice cream in an ice cream freezer know also that the ice cream mixture is placed in a metal container, around which is packed alternate layers of crushed ice and rock salt. Find out whether any one knows why these salts cause the ice to melt. (The salt lowers the freezing point of water.) What substances are used to lower the freezing point of water in automobile radiators? (Alcohol and antifreezes are put in radiators to lower the freezing point of the water in them.)

Encourage the pupils to think of different experiments they can do to discover if the seed meats they have been testing also lower the point at which water will freeze. One experiment they can try is to obtain four two-ounce medicine bottles that have at least one flat side. Put one tablespoonful of water in each. Add equal amounts of the black-eyed pea, lima bean, and sunflower meats to separate bottles. Also add an equal amount of water to the fourth or control bottle. Stir the seed meats into the water with a meat skewer. There should be enough mixture to cover the bulb of a thermometer. Place two of the four bottles in one metal ice cube tray. Place the remaining two bottles in another metal tray. (A can cover or a clothespin can be used to tilt the bottle of water so that the water in it will not spill.) Insert a thermometer into each of the substances and rest the thermometers on the edge of the trays. Make certain that the seed meats are packed around the bulb of the thermometer. Place the two metal trays in a freezer. Observe them at 30-minute intervals. When ice crystals can be detected in the seed meats with the meat skewer, record the temperatures of each of the substances. Observe that the temperatures of the seed meats are lower than the temperature of the water. When the bottles are removed from the freezer, observe how slowly the temperature of the seed meats rises. Keep probing the meats with a meat skewer or the blade of a screwdriver, and try to obtain thermometer readings when the ice crystals have melted. (These crystals should melt before the temperature rises above the freezing point.)

Summarize the results of the experiment. These seed meats do seem to have a substance in them that lowers the temperature at which any water that is in them will freeze. Why is this an important adaptation? (It is important because freezing could cause the seed coat to split and expose the embryo.) Let the children speculate whether the embryo has or has not any substance in it that lowers the temperature at which the water in its tissues will freeze.

7. What are some of the adaptations that enable some seeds to survive dormant seasons?

Have the pupils recall all the experiences they have had with seed adaptations. Ask them to list the adaptations they believe to be important to seed survival. Also ask them to state the reasons why these adaptations are important. Their list should include the following adaptations.

1. **Size and Number.** There is an inverse relationship between seed size and production. This relationship is important because, in general, small seeds are produced in larger quantities.

2. **Dryness.** A dry seed has a good chance of survival. If a seed is dry, the embryo will not germinate. A dry seed can survive very high and very low temperatures with very little damage. A wet seed cannot survive very high and very low temperatures.

3. **Seed Coat.** It protects the stored food and the embryo from damage by abrasions. It is also a poor conductor of heat and cold (an insulator). As an insulator, the seed coat keeps the inside of the seed warmer than its outside environment. Most of the surface area of a seed coat is waterproof. A partially waterproof seed coat will reduce the amount of water that can be absorbed by a seed.

4. **Stored Food.** The stored food in the cotyledons enables the embryo to be independent of its outside environment until it can manufacture its own food. The stored food also has substances in it that lower the freezing temperature of any water in its tissue.

5. **Location and Size of the Embryo.** The embryo is composed chiefly of protein. Protein lowers the freezing point of any water in the embryo. Because an embryo is partially embedded in the stored food, the stored food serves as an insulator. The part of the embryo *that is not embedded* in the stored food is protected by the insulating material that surrounds the hilum. The embryo is very small in comparison to the size of the seed and of the food stored in it. Dry seed embryos can survive freezing.

6. **Seed Insulators.** A dry seed is a poorer conductor of both heat and cold than a wet seed. The seed coat, the stored food, and the air in the seed are poor conductors (good insulators).

Some of the pupils may be interested in doing further experimentation with insulators. Encourage them to devise their own experiments. They may also like to try some of the following ones.

Which is a better insulator, air or water? Obtain two ice cubes which are approximately the same size. Put one cube in a paper cup that contains water at room temperature. Suspend the second ice cube in the air. Which melts faster? Why? (The ice cube which is in the cup of water will melt faster, because water is a better conductor of heat and cold than air.)

Which will freeze faster, water in a plastic bottle placed in a container of water or water in a plastic bottle which is suspended in air? Place one bottle of water in a metal can containing water. Place the second bottle of water in an identical can that is filled with air. Suspend these bottles in their cans of water or air by tying them to opposite ends of a 12-inch ruler. Lay the ruler on top of the cans. Adjust the height of the bottles so that they both will hang in the center of the cans. Be sure the water in the metal can is at the same level as the water in the bottle. Place the two metal cans in a metal ice cube tray, and put the tray in the freezer. Approximately one hour later, ice will form on the top of the water in the metal can. Two hours later, ice will begin to form on the bottle that is suspended in the can of water. At this time no ice will have formed on the water in the bottle that is suspended in air. It will take approximately four hours to freeze the water in this bottle.

When the water in both bottles is frozen, remove the tray from the refrigerator. Observe the melting process. Observations can be made at 30-minute intervals. In the bottle suspended in air, there will still be some ice ten to 15 minutes after all of the ice in the other bottle has melted.

What happens to water during the freezing process? Fill a plastic pill bottle level-full of water. Cover the top of the bottle with a piece of pliable plastic and tie loosely. Place the bottle where the water will freeze. About one and a half hours later, observe the change that has occurred. (The food wrap cover will bulge above the top of the bottle.) What caused the bulge? (The bottle is more than full.) What must have happened to the water during the freezing process? (It must have expanded.) What could happen to seeds that had been soaked by rain just before a very cold season began? (As the water in the seed expands during the freezing process, it could burst the delicate tissues of the embryo, split the seed coat open, and destroy the seed's stored food.)

Ask the pupils who did additional experiments to repeat them for the class.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Seed reproduction is the one method of reproduction common to all flowering plants.

2. As long as conditions favorable for growth remain unchanged, generation after generation of the same kinds of seed-bearing plants may continue to grow in the same region. The survival of these plants depends on: 1) the ability of the plants to produce seeds, 2) the ability of the seeds from these plants to survive, and 3) the ability of these seeds to germinate and grow into healthy seedlings. Foresters are applying this knowledge of seed production and survival to promote good forest management.

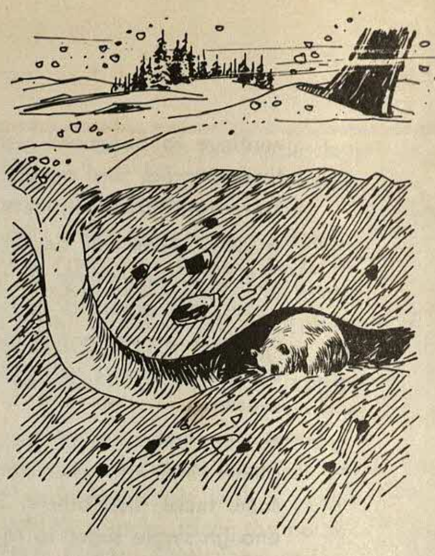
3. There seems to be an inverse relationship between the size and number of seeds that are produced by flowering plants. Plants that develop large seeds produce them in smaller quantities than plants that develop small seeds. This inverse relationship seems to be an important factor in the survival of flowering plants.

4. Some seeds are unable to survive the dormant season in areas where they are now cultivated, because they are not native. Plants from these seeds can continue to be grown year after year because the seeds are harvested, protectively stored, and annually replanted. Most plants that reseed themselves are native uncultivated plants.

5. Dry seeds will survive through the dormant season better than wet ones. The outer membrane of a seed is an adaptation that regulates the amount of water that enters or leaves the inside of the seed. When favorable amounts of moisture are present in the soil, seeds may germinate too early. If this happens, the young plants will not be able to survive either a hot dry or a cold dry season.

6. In some kinds of seeds, the stored food consists mostly of starch, whereas other kinds of seeds consist mostly of protein. All seeds tested stored fat, some more than others. The corn seed was the only seed tested that contained enough single sugar to react to the test used. The seeds that we tested proved to be poorer conductors of heat and cold than water. It is also possible that edible oils and proteins are poorer conductors than carbohydrates. All of the seed meats that were tested froze at a lower temperature than water did. The seed meats seemed to contain one or more substances that lowered the temperature at which the seed meats will freeze.

7. Both the inverse relationship that exists between seed size and production and the composition of the seed are adaptations that enable plants to continue to survive.



Chapter Forty-Six

Animal Adaptations for Surviving Seasonal Changes

Observing Animals During the Seasons when They Are Most Active and Least Active

INQUIRIES

1. What kinds of animals live in your region? During what times of the year are they most active? During what times are they least active?

2. What happens to fresh-water animals during the different seasons of the year?

3. What happens to land animals during the different seasons of the year?

The information, tables, and experiments included in this chapter should be helpful to teachers and pupils. Use the materials as guides to expand the depth and scope of the investigations of small animals. These materials are valuable for expanding the investigations *only when they are used as supplementary materials to pupils':*

observation of the most *active and least active* periods of these animals in their *natural habitat;*

collection and observation of live specimens;

experimentation that attempts to control and change the animal's natural environment;

exploration and duplication with live specimens of the factors that seem to affect seasonal changes in animals.

This skeletal chapter is presented in outline form. Chapters 12, 13, 14 and 15 contain additional material for investigating the questions in this chapter. This chapter is an introduction to the concept that animals around the world respond to seasonal changes.

1. What kinds of animals live in your region? During what times of the year are they most active? During what times are they least active?

Make an inventory of some of the animals in the community. This inventory should contain many of the animals listed in Table 46.1.

Have the pupils read, listen to stories, and watch television programs about animals. From these sources and others, children can collect information about the seasonal activities of animals.

Collect animal pictures and display them in the classroom. Have the pupils compose stories about animals. Make a tape recording of the children's stories and listen to them several times during the inquiry. Plan and take field trips to observe and collect small animals for further study in the classroom. These field trips should be taken at different seasons of the year.

Help the pupils build the vocabulary they need. Such terms as the following are important:

herbivores—plant-eating animals.
carnivores—meat-eating animals.
constant-temperature animals—most birds and mammals whose temperature is constant regardless of environmental temperature changes.
variable-temperature animals—insects, spiders, snails, clams, fish, amphibians, and reptiles whose temperature varies with environmental temperature changes.
migrate—the movement of animals from one location to another.
dormant—the inactive period of variable-temperature animals during *cold* weather.
estivate—the inactive period of variable-temperature animals during *hot, dry* seasons.
hibernate—the inactive period of some kinds of constant-temperature animals. (See Table 46.4.)

General observations about animals in regions where winters are severely cold

1. More animals are seen in the spring, summer, and fall than in winter.
2. Many kinds of animals feed on green plants. During the active growing season for plants, these animals are attracted to this plentiful food supply.
3. Many kinds of animals feed on other animals. They, too, are attracted to the actively growing green plant community by the plentiful food supply of smaller animals that it contains.
4. Spring is the time when many kinds of animals mate and reproduce their young. In spring, many kinds of animals (especially birds and mammals) rear their young.
5. In late fall and early winter, fewer animals are seen because some of the variable-temperature animals have sought shelter and have *become dormant.*
6. In late fall and early winter fewer animals are seen, because some have *migrated* to other regions.
7. In late fall and early winter, some kinds of constant-temperature animals have *hibernated.*
8. Some kinds of animals are seen at all times of the year. Some birds are year-round residents. Animals such as rabbits, gray and red squirrels, chipmunks, and deer are active all year unless the weather is inclement. Inclement weather may be heavy rainfall, heavy snowfall, or high winds.

General observations about animals in regions where there are both wet and dry seasons

1. Many animals are seen during the early part of the wet season.
2. Factors 1, 2, and 3 in the prior list also apply to animals in this region, if the words *wet season* are substituted for the words *spring and summer,* and if a *dry season* is substituted for *fall and winter.*
3. In the dry season fewer animals are seen, because some kinds have *migrated* to other regions.
4. In the dry season fewer animals are seen, because some kinds of variable-temperature animals have *aestivated.*
5. In the dry season *new and different kinds of birds* are seen, because they have migrated from the north into the region to stay for a time.
6. Factor 8 of the prior list applies to this region also.

General observations about the animals in regions where the temperature and rainfall vary little through the year

1. Many of the same kinds of animals are seen through the entire year.
2. Many different kinds of insects are seen feeding on the blossoms and tender leaves of green plants.

Table 46.1

A RECORD OF THE ANIMALS WE SAW ON A TRIP TO THE WOODS ON ____

(PARK, GARDEN, FIELD, OR WOODS) (DATE)

Note: This record has been filled out as an example of what children can see in a deciduous forest.

Common Name of Animal	Class of Animal	Expect to See	Did See	Number Seen	Where Seen	Childrens' Comments
Garden Slug	Snails and slugs	X	X	1 (1)	On the ground under dead leaves.	We think it is resting. It may feed at night.
Land Snail	Snails and slugs	X	X	1111 (4)	On green leaves of bushes.	They eat holes in leaves.
Centipede	Centipedes	X	X	11 (2)	On the ground under some rotting wood.	It had so many legs, we couldn't count them.
Ant	Insects	X	X	many	Running in and out of ant hills; running everywhere.	We counted 20. There were many, many more than that.
Bee, Bumble	Insects	X				
Bee, Honey	Insects	X				
Beetle	Insects	X	X	111 (3)	On the ground and on the leaves of a bush.	We saw different colored and different shaped beetles. There may be many kinds of beetles.
Butterfly	Insects	X	X	11 (2)	When we arrived, some were flying and others were on flowers.	We saw different colored butterflies. What are their names?
Fly, House	Insects	X	X	~~1111~~ (5)	They buzzed around us when we stopped to rest.	Flies must be everywhere. They are wherever we go.
Fly, Deer	Insects	X				
Grasshopper	Insects	X	X	~~1111~~ (5)	In the grass	One of them flew into the air. We saw brown and yellow on the wings. Some just hopped away.
Mosquito	Insects	X	X	many	Some of them flew out of bushes.	We got mosquito bites. Peter killed one that was sucking blood from his arm.
Moth	Insects	X	X	11 (2)	On the bark of a tree.	They looked just like the bark. We saw them when we were looking for cocoons.

Wasp	Insects	X	X	111 (3)	They buzzed around us when we were sitting listening for animal sounds.	Wasps are skinnier than honey bees. They didn't sting us because we sat very still.
Toad	Amphibian	X	X	1 (1)	Under a tree, on some damp leaves.	We tried to make it hop. It just tried to make itself smaller and sat very still.
Salamander	Amphibian	X	X	1 (1)	On the ground under a rotten branch.	It was very long and thin and its skin looked wet.
Turtle	Reptile	X	X	1 (1)	Near the path in the woods.	It closed its shell up tightly when Robert picked it up. The teacher said it was a box turtle.
Black Snake	Reptile		X	1 (1)	Sunning itself on some rocks.	It crawled away very fast when we tried to get nearer. It was a very little snake.
Garter Snake	Reptile	X				
Cardinal	Bird	X				
Catbird	Bird	X	X	11 (2)	We heard one and we saw one flying through the underbrush.	It is thinner than a robin. Part of its song does sound like a cat.
Crow	Bird	X	X	111 (3)	We saw one crow in the top of a tree. We heard two say caw-caw.	A crow is a noisy bird. We think we saw a crow's nest in the top of a tree.
Wood Peewee	Bird	X	X	1 (1)	We heard it sing. It was in a tree near us. It flew in and out of the tree.	We think that it was catching insects, when it darted in and out of the tree.
Squirrel	Mammal	X	X	1 (1)	We saw it eating beechnuts under a beech tree.	It was trying to get the nuts out of the beechnut bur.
Chipmunk	Mammal	X	X	1 (1)	Running under the trees.	It looked at us and ran away. We think it was looking for nuts too.

Table 46.2

SMALL ANIMALS WHICH LIVE EITHER ALL OR PART OF THEIR LIVES IN FRESH WATER

Back swimmer
Black fly
Caddis fly
Clam
Crane fly
Crayfish
Damsel fly
Diving beetle
Dobson fly
Dragon fly
Fish
Fresh water mite
Frog
Giant water bug
Haliplid beetle
Leech
Mayfly
Midge
Mite
Mosquito
Mussel
Polliwog
Pond salamander, common
Pond snail
Stone fly
Toad
Water boatman
Water scavenger beetle
Water scorpion
Water sowbug
Water strider

Table 46.3

SOME KINDS OF FRESH WATER FISH AND WHERE THEY LIVE

Name of Fish	Weed Clogged Ditches and Small Ponds	Small Ponds	Slow Warm Rivers	Slow Cool Streams	Deep Cool Lakes	Shallow Lakes or Shores of Deep Lakes
Bluegill		X	X			X
Brook Trout				X		X
Brown Trout				X		X
Bullhead		X				X
Carp	X	X	X			X
Common Shiner	X		X			
Crappie		X				X
Dogfish		X				X
Fallfish						X
Garpike						X
Golden Shiner	X	X				
Horned Dace	X	X	X	X		
Killifish	X	X				
Lake Trout					X	X (in spring)
Largemouth Bass		X				X
Lamprey		X	X	(in spring) X		X
Mud Minnow		X				
Muskellunge					X	X
Pickerel		X	X			X
Pike						X
Pike Perck						X
Pumpkinseed		X	X			X
Rainbow Trout					X	X
Rock Bass		X				X
Sawbelly					X	X
Shiner						X
Smallmouth Bass		X			X	X
Stickleback	X					
Sturgeon						X
Sucker				X		X
White Perch		X				X
Yellow Perch		X				

3. On the green plants many different kinds of spiders are seen waiting to catch the insects on which they prey and feed.
4. Many egg cases, larvae, and cocoons are seen.
5. Bird songs are common. Birds sing more during the mating season.

2. What happens to fresh-water animals during the different seasons of the year?

Chapters 12, 13, 14, and 15 contain suggestions for collecting housing and caring for small animals. Find out whether the pupils have had the experiences suggested in these chapters. If they have, they should be able to assume major responsibility for helping to plan and conduct field trips to places where fresh-water animals live.

During the planning period, make an inventory of the fresh-water animals which live in the community. The inventory should include many of the fresh-water animals listed in Tables 46.2 and 46.3. The animals listed in Table 46.2 spend either part or all of their life in fresh water.

After collecting and stocking the homes of the fresh-water animals, plan and do experiments similar to the ones in the two inquiries that follow. *Are aquatic animals more active at 70–80 or at 50°F?* During this experiment, each pupil should observe and note the kind and degree of activity which the animals in an experimental aquarium display. Check and record the temperature of the water in the container.

By adding ice cubes one by one, and by gently stirring the water, the water temperature of the aquarium can be lowered to 50°F. Observe and record any changes in the activities of the water animals.

What changes occur? (The animals move more slowly. The animals stop feeding. Fewer water insects come to the top of the water. Why? They come to get air. Because they use less air when they are less active, they come to the top less frequently when the water is cooler. Cold water also contains more air than warm water.)

Allow the water to return to room temperature. Observe and note the kind and degree of animal activity. (Activity should return to what it was before the temperature was lowered.)

Are aquatic animals more active at 90°F? or at 70–80°F? Observe and note whether animal activity increases, decreases, or remains unchanged when the temperature of the aquarium water is raised to 90°F. To raise the temperature in the aquarium, pour boiling water into either a Pyrex beaker or a measuring cup. Lower the cup of hot water, right side up into the tank of water. Stir gently to add a little hot water at a time to the tank water. What changes in animal activity can be noted? (For most of the animals there will be decreased activity. Snails may move to the bottom and close their shells. Water insects may come more frequently to the surface for air.)

How cold does the water get at the bottom of a lake that is covered with ice? (In bodies of water that are frozen over and are six or more feet deep, the temperature of the bottom water *will* be about 40°F. In very deep bodies of water, the temperature will be higher.)

Can you guess whether fish will move into shallow or deep water when the surface water temperature is over 80°F; when it is less than 50°F? (Fish will move into deeper water.) Why? (The temperature of the deeper water is less affected than that of the surface water by changes in air temperature.)

3. What happens to land animals during the different seasons of the year?

Use the following materials to clarify the pupils' concepts regarding animals that *migrate;* animals that *hibernate;* animals that become *dormant;* and constant-temperature animals that *become less active during the most inclement weather.*

In general, *the variable-temperature animals become dormant* and *some of the constant-temperature animals hibernate.*

Some interesting information about the states of dormancy and hibernation

Animals have many adaptations and instincts that enable them to live all through the year in the temperate zone. Some animals survive the cold weather in a state of *dormancy*, others in a state of *hibernation*, and some become *inactive for several or more weeks* during the very coldest and stormiest of weather. *Constant-temperature* animals *migrate, hibernate,* or become *inactive during the coldest and stormiest weather. Variable-temperature* animals survive in a state of *dormancy.*

Hibernation

Some kinds of birds and mammals hibernate. Birds and mammals are constant-temperature animals. Currently the term hibernate is applied only to constant-temperature animals, whereas formerly the term was more loosely used. It was customary to use the term when referring to any kind of animal that became dormant or inactive for most or part of the cold season in the temperate zone. For this reason, the pupils may find that reference books do not always agree with the list of nonhibernators and true hibernators included in this inquiry.

Table 46.4 lists the names of some nonhibernators and some true hibernators and Table 46.5 gives the lowest and highest body temperatures at which some of them can survive.

A hibernating animal continues to be sensitive to stimuli in its environment throughout the hibernating period. A probe with a pencil will cause it to react. The digestive tract of a hibernating animal collapses and the digestive glands become inactive. The teeth become degenerative. The activity of all life-producing processes is decreased but can still be detected. A hibernating animal, with the exception of an insect-eating bat, assumes a typical hibernating position.

Chimney swift and hummingbird are two birds that hibernate in certain regions of the temperate zone. A number of different kinds of mammals hibernate. (See Table 46.4.)

Table 46.4

SOME DORMANT AND HIBERNATING ANIMALS

Dormant	Hibernating
Fish	Bat
Frog	Doormouse
Insect	Groundhog
Salamander	Hamster
Snake	Hazel Mouse
Spider	Hedgehog
Toad	Hummingbird
Turtle	Marmot
	Pocket Mouse
	Poorwill
	Swift, chimney
	Woodchuck

Table 46.5

RANGE OF BODY TEMPERATURES WITHIN WHICH MAN AND SOME ANIMALS CAN SURVIVE

Name of Animal	Temperature Range in °C	Temperature Range in °F
Bear	32–38	90–100
Frog	0–20	32– 68
Ground Squirrel	0–38	32–100
Hamster*	7–38	44–100
Man	22–41	72–106
Poorwill	2–44	36–111

* This animal's tolerance to variation in temperature was tested in a room in which the temperature of the room could not be lowered below 44°F.

Inactivity during severest weather

Some kinds of mammals become inactive for several or more weeks during the coldest and stormiest weather. Many of these mammals have thick coats of fur and live in sheltered places that are protected from wind and cold. These kinds of animals that are dependent upon this method for surviving the winter cold will vary from one region to another. However, some of the animals in this list will be found in most regions (field mice, rabbits, chipmunks, racoons, beavers, muskrats, foxes, bears, and bobcats). These constant-temperature animals have an outer covering that enables them to conserve body heat. Nonmigratory birds and mammals molt. They grow thick winter coats which act as insulators and help keep their bodies warm.

Dormancy

Dormancy is another method that enables animals to survive cold weather. While animals are in a state of dormancy, their body temperatures can fall well below what it is when they are active. When this happens, all their body processes slow down. In this condition they can survive the cold if their body temperatures remain slightly above the freezing point.

Variable-temperature animals, such as amphibians, reptiles and some adult insects find a sheltered place and become dormant. The eggs, larvae, and pupae of many kinds of insects survive freezing weather in a state of dormancy.

Dormancy and Insects. Insects, like other variable-temperature land animals, survive cold weather by becoming dormant. They survive the winter in one or more stages of their life cycle. (See Table 46.6.)

Some Insects Survive the Winter in the Egg Stage. Such insects as moths, butterflies, beetles, dragon flies, and praying mantises survive low temperatures in the egg stage. Many kinds of insect eggs will hatch even though they have been frozen solid. In fact, some kinds of insect eggs will not hatch until after they have been exposed to freezing temperatures. The egg masses of the tent caterpillar can be found buried in a thin shellaclike mass on the branches of fruit trees and on some kinds of shade trees. Praying mantis eggs are encased in a cradle of hardened foam, which is spun by the female moth. (See Chap. 14, Inquiry 1.) The egg masses of the saddleback caterpillar moths and the gypsy moths can be found under loose tree bark, on the walls of buildings, under rocks, and so on. The eggs of some kinds of bees and moths are encased either in a paperlike sack made from the saliva of the female or in mud. These egg cases can often be found attached to the walls and under the eaves of buildings.

Collect and Observe Insect Eggs. After prolonged cold weather, collect some insect eggs. Place them in covered transparent containers. Keep in a warm place. Watch for hatching of the eggs.

Some Insects Survive Through the Winter in the Larval Stage. In the middle latitudes of both northern and southern hemispheres, some kinds of beetles, butterflies and moths survive the cold weather in the larval stage. Butterfly and moth larvae are called caterpillars. Beetle larvae are usually referred to as *grubs.* The black and orange woolly bear caterpillar is often found curled in dead tree leaves. Different kinds of beetle larvae can usually be found in decaying wood, beneath the bark of trees, and in the soil.

Collect and Observe Larvae. Dig a few shovelfuls of soil in a garden, a field or in the woods. In this soil, white grubs (larvae) may be found. Beetle grubs may also be found inside decaying logs. Take the soil samples and the decaying wood to the schoolroom. Careful examination should disclose eggs, *larvae*, pupae and adults of many kinds of insects. Place samples of the soil and the decayed wood in large-mouthed glass jars. Moisten the samples and screw the lid tightly on each container. Put the jars in a dark cool place or in a refrigerator. Examine the wood and soil after they have been there for several weeks. Observe if any animals are active in the jars. Return the jars to the same cool place until the next growing season arrives. Then return the jars to the classroom. After a week or ten days, examine the contents of the jars. It may be that several different kinds of animals can be seen moving around. Such animals may be tiny grasshoppers, crickets, flies, and small beetles.

Some Insects Survive Through the Winter in the Pupal Stage. Many different kinds of insects survive cold weather in the pupal stage. These pupae may be found in the soil, under the bark of trees, in wood, under stones, and attached to the branches of trees and to the outside walls of buildings. Pupae that are not encased in silk are called either pupae or chrysalides. The naked pupae of such animals as moths, several kinds of bees, wasps, and flies are called *pupae.* The naked pupae of butterflies are called chrysalides (singular—chrysalis).

Pupae that are covered with silk are called *cocoons.* One or more cocoons can usually be found attached to the outside of most buildings.

The pupa stage (cocoon) of such moths as the saddleback caterpillar and gypsy may also be found attached to the outside of buildings. The thin silk cases of these cocoons are embedded in a mattress of hairs from the body of the caterpillars that formed them.

Collect and Observe Pupae. Use a paring knife to remove several of these cocoons. Open one of the cocoons by carefully removing the outer silk covering with the knife. Observe the brown chitinous covering of the pupa case. Examine the outside of the case with a magnifying glass. Note that the head, thorax, abdomen, and wings can be seen. The antennae (feelers) also can be identified readily. Some kinds of pupae will wiggle when their abdomens are touched or when the pupa is warmed by the heat of the hand.

Place several inches of moistened soil in a wide-mouthed glass jar. Put a twig in the jar. Place the bare pupa case in the jar and cover it with a thin layer of soil. Lay the other cocoons on top of the soil and screw the lid tightly on the jar. Place the container in the coolest place in the room where it will receive some sunlight.

Table 46.6

SOME KINDS OF INSECTS AND THE STAGES IN WHICH THEY SURVIVE BELOW-FREEZING TEMPERATURES

		Stages in Life Cycle*			
Small Groups or Orders	Common Name	Adult	Egg	Larva or Nymph	Pupa
Beetles (Coleoptera)	Crickets		X		
	Diving Beetles	X			
	Ladybird Beetles	X			
	Fireflies				X
	Tiger Beetles		X		
	Japanese Beetles			X (larva)	
	May Beetles				X
	Weevils	X			X
	Whirligig Beetles	X			
Bees, Wasps, and Ants (Hymenoptera)	Bumblebees	X (queen only)	X		
	Honeybees	X			
	Papermaking Wasps	X (queen only)			
	Mud Dauber Wasps	X			
	Potter Wasps	X			
	Ants	X			
Bugs, True (Hemiptera)	Squash Bugs	X			
	Chinch Bugs	X			
Caddis Flies (Tricoptera)	Caddis Flies			X (larva)	X
Dragon Flies and their Kin (Aniscoptera)	Dragon Flies			X (nymph)	
	Damsel Flies			X (nymph)	
Flies and their Kin (Diptera)	Crane Flies	X	X	X	
	House Flies	X	X	X	X
	Mosquitos	X	X		
	Robber Flies			X (larva)	
	Horse Flies			X (larva)	X
	Deer Flies			X	X
	Blue Bottle Flies	X		X	X
	Green Bottle Flies	X		X	X
	Fruit Flies	X		X	X
	Gall Flies	X		X	X
Grasshoppers, Katydids, Roaches and their Kin (Orthoptera)	Grasshoppers		X		
	Roaches		X		
	Praying Mantises		X		
	Katydids		X		
	Walking Sticks		X		
Leafhoppers, Aphids and Scale Insects (Homoptera)	Treehoppers		X		
	Leafhoppers		X		
	Cicadas		X	X (larva)	X
	Aphids		X	X (larva)	X
	Scale Insects		X		
Mayflies (Ephermida)	Mayflies		X		

Moths and Butterflies (Lepidoptera)	Codling Moths			X (larva)	
	American Silkworm Moths				X
	Corn Earworms or Cotton-Boll Weevil				X
	Sphinx Moths				X
	Tent Caterpillar Moths		X		
	Copper Butterflies		X		X
	Blue Butterflies		X		X
	Monarch Butterflies	migrate			
	Mourning Tail Butterflies	become dormant			
	Swallowtail Butterflies				X
Nerve-winged Insects (Neuroptera)	Lacewings	X (some species)			
	Dobson Flies (also called Hellgrammites)			X (larva)	X
	Ant Lions			X (larva)	X
Stone Flies (Plectoptera)	Stone Flies			X (larva)	X

* X = stage in which they can be dormant and survive.

Near the end of the dormant season, a moth may emerge from each of the cocoons. It is also possible that a moth may emerge from the bared pupa case. The emerging moths will crawl up the twig and slowly flutter their wings until they are completely dry.

If a female emerges from one of the cocoons, she will lay eggs even though the eggs have not been fertilized. Should both males and females emerge, they will *copulate*. During copulation sperms from the male moth will enter the abdomen of the female and fertilize her eggs. A day or two after copulation, the female will lay her eggs. Approximately one week later the eggs will hatch.

As soon as a moth emerges from its cocoon, it should be placed in an insect cage. If the moths are clinging to the twig, remove the twig and place it in the cage. Should the moths be on the soil, push a piece of paper under them and move them to the cage.

The pupils may be interested to know how they can distinguish a male from a female moth. It is easy to identify them if there are two to compare but the identification is more difficult if there is only one. The abdomen of the male moth is much smaller than the fermale's. If the moths have featherlike antennae the female's will be longer and wider than the male's. Should there be only one moth, it may be necessary to ask the biology teacher or some other specialist for help.

Some Insects Survive the Winter in the Adult Stage. Some kinds of butterflies and moths survive cold weather in the shelter of decayed tree stumps, in fence posts, under bark, rocks, or wood which are lying on the ground. On clear sunny days in late winter or early spring, mourning cloak butterflies may be seen flitting around the edges of woods, in swamps, and in meadows.

In winter, different kinds of moths often may be found by pulling off the loose bark of trees. However, most adult butterflies, moths, and other insects have neither the instincts nor the adaptations that enable them to survive freezing temperatures. Their survival is usually dependent upon the adaptations of their egg, larval, or pupal stages.

In cold weather honeybees cluster in a loose mass in their hives. As many as 50,000 honeybees may form one cluster. The motion of their wings and legs keeps the temperature of the hive well above the freezing point. The temperature in the center of the cluster may be 50°F or higher. When the bees on the outside of the cluster get too cool, they burrow in toward the center.

Observe Adult Insects. If possible visit an apiary on a cold day. Have the pupils take turns pressing their ears against the hive to listen to the faint hum of the bees inside. Also plan to take one or more field trips during months when the ground is bare and when the temperature has continued below 50°F for several consecutive days. The pupils may find thousands of insects huddled together under stones, boards, in attics, and in warehouses. These clusters of insects will be several inches thick. The heat radiated by these large clusters increases the temperature sufficiently and prevents their freezing. During the cold weather, mice are frequently found in beehives, where they are warmed by the radiated heat of the bees. Also the radiated heat of the mice increases the temperature in the hive.

Dormancy and Spiders. The adults of many kinds of spiders which live where temperatures fall below freezing die at the end of the growing season. These species of spiders survive the dormant season in the egg stage of their life cycle. The eggs are encased in a covering of silk, which is spun by the female spider. These egg cases can be found attached to tree bark and to the sheltered sides of buildings.

Migrators. To what three classes do the land animals which make long migrations belong? (*Insects:* Monarch butterfly; *Birds:* arctic tern, Canada goose, golden plover, swallow; *Mammals:* lemming.) To what four classes do land animals that make short migrations belong? (*Insects:* migratory locust also called short-horned grasshopper, ladybird beetle, soldier ants; *Amphibians:* toads, frogs, salamanders; *Birds:* cardinals, robins, crows; *Mammals:* bison, buffalo, deer, elephant, mountain goat and sheep, moose, reindeer.) Discuss and summarize the collected information. The following questions may help to direct the summary. Which animals hibernate? Do the hibernators have variable or constant temperature? Which animals become dormant? To what group or class do the animals that go into a state of dormancy belong? Are animals that become dormant variable- or constant-temperature animals? What two classes of animals are inactive only during the coldest and stormiest weather? (*Birds:* woodpecker, English sparrow; *Mammals:* chipmunk, gray squirrel, red squirrel, rabbit, field mouse.)

See the chapter summary of process skills on the back endpapers of this book for process skills that can be practiced while developing the inquiries in this chapter.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Mammals, birds, reptiles, amphibians, fish, insects, spiders, and so on, are common to most regions. Sponges, corals, worms, and crustaceans also are commonly found.

In regions which have prolonged cold winters with temperatures frequently below 32°F, the summers will be the time when the animal life of the region is most active; winter when it is least active.

In tropical and subtropical regions, where there is both a rainy and a dry season, animals will be most active in the wet season and least active in the dry season.

Some animals migrate, some hibernate, some aestivate, some become dormant in sheltered places, and some continue limited activity, except during the most inclement weather. Hibernators are always constant-temperature animals. Those animals that seek shelter and become dormant, or in dry seasons aestivate, are the variable-temperature animals.

2. There is a variation in the activities of variable-temperature water animals.

When the water temperature is either very high or very low, the animal activity decreases. Fish move into deeper water when the surface water temperatures are either too high or too low for them.

3. Animals have many adaptations and instincts that enable them to live either a part or all of the year in the temperate zones. Many kinds of birds and mammals and certain insects avoid cold weather by migrating to warmer climates, in the fall of the year.

Many constant-temperature animals migrate, hibernate, or become inactive during inclement weather. Most hibernating animals tuck their heads and legs under them and assume a shape like a ball. However hibernating animals react to outside stimuli. Adult variable-temperature amphibians and reptiles survive the winter season by finding shelter and becoming dormant. The state of dormancy differs from hibernation in several ways. Dormant animals assume shapes that are typical of their resting position. Dormant animals do not react to stimuli.

The adults, eggs, larvae, and pupae of many kinds of insects survive freezing weather in a state of dormancy. Many kinds of adult insects die before the winter season in the temperate zones. Survival of these insects depends upon the adaptations of their eggs, larvae, and pupae.

Chapter Forty-Seven

Migrators

INQUIRIES

1. Which birds in the region are year-round residents? Which ones migrate sometime during the year?

2. What routes do bird migrators follow? What kinds of birds take these different routes?

3. What kinds of animals other than birds migrate?

4. What different types of migration are there? When do animals migrate?

1. Which birds in the region are year-round residents? Which ones migrate sometime during the year?

Pupils and teachers, from their personal observations and knowledge, should prepare a tentative list of *bird migrators and bird nonmigrators.* Use regional and state resources, books, films, and people to revise and add to the tentative list. Factors that affect migrators and nonmigrators are latitude, altitude, climate, proximity to bodies of water, kind and abundance of either plant or animal food, and so on.

Use a variety of educational techniques and methods and all the resources of your community and state to help pupils attain the following skills and learnings concerning birds in their area.

1. To identify the birds listed.
2. To recognize their songs and calls.
3. To know their nesting and feeding habits.
4. To learn how to build a bird feeding station, and to know where to place it so that the birds can be observed and studied when they come to it seeking food.
5. To seek further information by visiting area sanctuaries and state or national parks where birds are protected, and by talking with the persons in charge.
6. To study birds in museums where there are worthwhile bird displays.
7. To visit an aviary for firsthand observation of birds.
8. To determine if, in winter, area birds feed heavily before storms, during storms, or after storms.
9. To discover where birds find shelter during severe cold and storms.
10. To discover the adaptations that nonmigrators employ to survive cold weather.
11. To understand the various physical differences among birds, which are adapted to their specific ways of life.
12. To keep yearly calendar records of the kinds and numbers of birds frequenting a single bird feeding station, in order to date the arrival and departure of migrators.
13. To know what flyway or flyways the regional migrators use.
14. To know both the nesting and feeding ranges for regional migrators and nonmigrators.
15. To learn how bird watches, bird counts, bird banding, and so on, are helping to furnish information about birds.
16. To explore the unsolved problems of bird migration and the methods used by scientists to expand our present knowledge.
17. To keep a record of all observations, facts, and information pertaining to each kind of bird.

Summarize the information that is pertinent to the inquiry. Discuss the fact that birds that are winter residents in the north temperate zone have two layers of feathers. The outer layer protects the bird from rain, snow and wind. It also gives the bird its characteristic contour and color. The inner layer is soft, fluffy, and downy. This layer traps and holds the heat which the bird's body radiates. These two layers are scarcely an inch in thickness. Yet the temperature range from the outer surface of their feathers to the inner surface next to the skin may vary from below 0 to 100°F. The feathers of the ruffed grouse, also called bobwhite and partridge, are an almost perfect heat trap.

If possible obtain a partridge from a hunter and examine these two layers of feathers. Also examine some of the feathers with a microprojector.

This next experiment was invented by students. Try it. Obtain two round covered ice cream cartons, two glass baby food jars, two thermometers, and some cotton batting. Put hot water in each of the jars. Record the water temperature. Quickly place the water jars in the ice cream cartons. Pack one carton with batting *that has been pulled apart* to make it more "downy." Pack the other with *compressed batting*. Cover. At 15-minute intervals, remove the covers and quickly record the temperature. In which packing does the water remain warm longer? Why? Which packing simulates the downy layer of a bird's feathers?

2. What routes do bird migrators follow? What kinds of birds take these different routes?

General information about bird migrators and their flyways is developed in this inquiry.

Some interesting information about bird migration

North America has four migratory flyways. See Figs. 47.1, 47.2, 47.3, and 47.4.

1. The Atlantic Flyway. This flyway stretches from the Arctic Ocean to the Atlantic and southward as far as Argentina in South America. (See Figure 47.1.) As the map indicates, birds from many parts of North America follow this route. Some kinds of shore and water birds fly southward over many miles of open ocean. Ducks, geese, sandpipers, and herons migrate *over the open Atlantic Ocean*. Because this flyway extends over both Bermuda and the Sargasso Sea, the birds that use the ocean route can stop in these places and either rest or feed, or both.

Many kinds of land and water birds, who have nesting ranges in New England, New York, Michigan, Illinois, Indiana, and states along the Atlantic Ocean, follow the *Atlantic coastline* southward to their winter feeding ranges. There are many protected bird sanctuaries through the southland. One sanctuary, the Everglades National Park, in south Florida is a protected winter range for many kinds of northern birds. It is also a protected rookery for other kinds of birds. Many kinds of birds nest in this park in the wintertime.

Much of this coastal flyway between the northern and southern states is not too difficult. However, it becomes more difficult to follow this flyway where it extends into South America.

2. **The Mississippi Flyway.** This flyway spreads out like two large funnels placed with their pointed ends together. (See Fig. 47.2.) More bird migrators use this flyway than any of the others. It is one of the longest migratory routes in the western hemisphere. One part of the route leads from Alaska's arctic coast to the southern tip of South America. Some shore birds fly the entire length of this flyway. Barn swallows and nighthawks also follow most of the route.

This is a broad, easy flyway that has an abundance of food and many trees that provide shelter. There are no mountains and deserts, which are hazardous to bird migrators. Most of the birds using this route spend the winter in the Gulf states of the United States.

3. **The Central Flyway.** This flyway extends from the Arctic Ocean southward over the great plains into Mexico and Central and South America. (See Fig. 47.3.) Many water birds, as well as land birds, who nest on the great plains, use this flyway. The United States and Canadian parts of this migratory route have plenty of food, adequate rest areas and few natural hazards.

4. **The Pacific Flyway.** This flyway is used by birds that either live near, or on, the western coast of the United States. (See Fig. 47.4.) Not many western birds migrate. When they do, the distances they travel are usually shorter than those traveled by birds on the other flyways. One part of this route follows the Pacific Coast of the United States, Mexico, and Central America. A second branch over the Pacific Ocean is used by birds from Siberia, Alaska, the Aleutian and Pribilof Islands. It extends over 2000 miles of the Pacific Ocean to Hawaii. This hazardous route is used by only a very few birds, in addition to the golden plover. In August and September the plovers fly this long flyway south nonstop in approximately two days. They return north over the same flyway in April and May to nest. Their average speed is 35 to 45 miles per hour.

Famous long-distance bird migrators

Blue geese and the Atlantic and Pacific golden plovers fly distances as great as 2000 miles. However, this distance is small compared to the distance the Arctic tern travels when migrating. The Arctic tern, because it nests in the Arctic during the late spring and summer months and migrates to the Antarctic during the winter months, seldom experiences darkness. The tern's nesting range is located along the northern coasts of Asia, Europe, and Canada; but in winter they are widely distributed over the south Atlantic, Pacific and Indian Oceans. These birds travel a distance of 24,000 miles annually.

Short-distance migrators

Most birds make short journeys. The summer and winter ranges of some birds are so close together that they overlap. Where ranges overlap, the same kinds of birds stay the year around, *but they are not always the same birds.* There are robins and field sparrows the year around in Virginia, but they are not the same robins and field sparrows. Those that live there in the summer move farther south in the fall and their places are taken during the winter by those robins and field sparrows whose nesting range is farther to the north. However magpies which stay are the same ones.

Night and day bird migrators

Most bird migrations occur at night. Small birds usually migrate at night. This is particularly true of birds that feed on insects. Flycatchers, most kinds of warblers, orioles, and other small perching birds such as wrens and bluebirds are night migrators. Many water fowls, shore birds, terns, and songbirds also fly under cover of darkness.

Such birds as hawks, doves, swifts, swallows, crows, seed-eating sparrows and finches, herons, ducks, and geese tend to travel long distances by day.

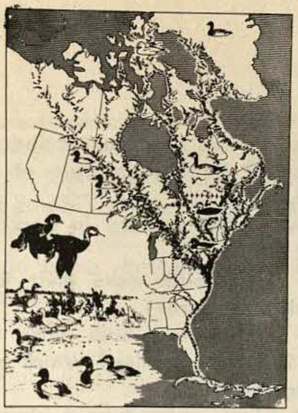


Fig. 47.1 The Atlantic flyway. *Figures 47.1, 47.2, 47.3, and 47.4 courtesy U.S. Department of the Interior, Fish and Wildlife Service.*

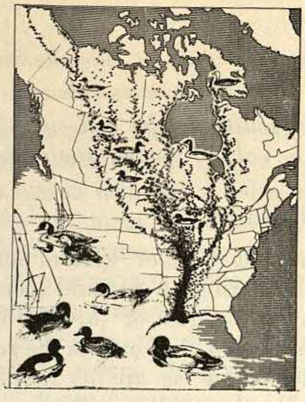


Fig. 47.2 The Mississippi flyway.

Fig. 47.3 The central flyway.

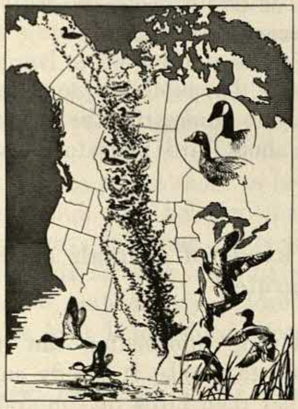
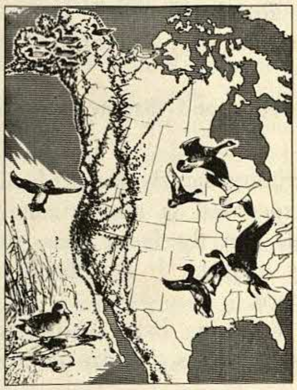


Fig. 47.4 The Pacific flyway.



Migration directions

The statement that birds in the north temperate zone tend to migrate south in the fall and north in the spring is generally true. However, there are exceptions. Some birds, such as chickadees and juncos, make very short migrations from highlands to lowlands. They nest in the highlands in the spring and summer and migrate to their feeding ranges in the lowlands in the fall.

In the tropical rain forest where there is little long distance migration, there are seasonal shifts from one source of food to another during the rainy and dry seasons. The migration of oceanic birds may occur in almost any direction. The white-fronted terns that nest in New Zealand migrate almost due west in the fall to winter along the east and southeast shores of Australia. The red-headed ducks that nest along the shorelines in the prairie states of the United States migrate eastward to their winter range along the Atlantic coast. The rose-colored starling that winters in India flies northwest to nest in the grasslands of Turkey and southern Russia.

In the southern hemisphere, where warmer climates are located in the north, very few land birds migrate and very little is known about their migrations. The Adelie penguins that nest in the Antarctic migrate north in the fall. Penguins cannot fly, but they are excellent swimmers and migrate by swimming. They spend their winters at sea. In the spring when they return, they may walk 50 or more miles over frozen shorelines to reach their rookeries. Emperor penguins also breed in the Antarctic. They, however, travel *south in the fall and hatch their chicks in the cold of the Antarctic* winter.

An unusual migrant

The Kirkland warbler winters on only one island in the Caribbean Sea and spends its summers in a small area of the Huron National Forest in Michigan. Not only is the range of this bird restricted, but so are its nesting requirements. Kirkland warblers will nest only under the lower branches of young Jack pines. Jack pines reproduce only after *a forest fire.* The fewer forest fires, the fewer the Jack pines, and the fewer the nesting places for the warblers. Now a special area has been set aside for the preservation of this bird. Each year, one section of these Jack pine forests is burned so that there will always be small young Jack pines under which the warblers can nest.

Average speeds and distances traveled by migrators

The maximum hourly speed of migration that has been recorded is approximately 50 miles. Many birds can fly faster than the speeds at which they migrate. It is difficult to determine a bird's speed.

See the following list of birds for the average number of miles they travel per day.

NAME	MILES PER DAY
Common tern	125
Gannet	100
Herring gull	60
Laysan albatross	100
Leach's petrel	30
Manx shearwater	200
Pacific plover	1000
Starling	25
Swallow	150

Again use different educational techniques, methods, resources, and people to help pupils explore these questions for pertinent answers.

1. To which state or country do the different kinds of migratory birds of the region go?
2. What are the routes called which birds follow, when they are migrating? Where are they located?
3. Which birds migrate to warmer climates at the end of the growing season and return north at the beginning of the next growing season? Do birds migrate at other times? When?
4. Which birds migrate in flocks? Which do not?
5. Do young birds make their first migration with older birds?
6. Do all migratory birds make long journeys of 200 or more miles? Which ones do make long journeys?
7. What birds make nonstop migrations? What birds stop, rest, and feed during their migrations?
8. When are the most migrations made—at night or during the day?
9. At what average speed do birds fly when they are migrating?
10. What average daily distances can and do birds cover when they are migrating?
11. Are all bird migrations limited to the same seasons of the year?

Work with the pupils on some original and colorful way to summarize the information they now have about bird migrators and their flyways.

3. What kinds of animals other than birds migrate?

The following information can be useful to teachers and to pupils. It briefly suggests some animals other than birds that migrate. The capsule case histories could serve pupils as patterns for developing the case histories of other interesting migrators such as the grunion, the pink shrimp, and so on. The brevity of the case histories should stimulate some pupils to explore a specific animal's migratory pattern in greater depth and to find pictures depicting phases of this migration.

If teachers and pupils are fortunate enough to live where they can observe any phase of the migratory pattern of an animal, they should make plans to do so.

Some interesting information about the migrations of amphibians, crustaceans, fish, insects, reptiles, and mammals

Amphibians

No variable-temperature animals are active in cold weather. They usually become dormant.

Some find shelter in mud at the bottom of ponds. Others work themselves deep into soft moist earth. Most amphibians, such as frogs, toads, and salamanders, are not long-distance migrators; but many do make short-distance migrations at breeding time.

Crustaceans

Fiddler Crabs spend most of the year in dry beach sand. The female carries her eggs attached to the underside of her body. In spring just as the eggs are about to hatch, the female moves close to the ocean's edge. As each baby crab emerges from an egg, the mother flips it into the ocean. The young crabs live in the sea until they are adult. In the West Indies, where land crabs live a mile or more inland, it is a wonderful sight to watch their annual migration to the sea. They crawl to the sea in one long parade.

Horseshoe Crabs have been living in the ocean for millions of years, and they have changed very little during their long tenure there. They move from the sea to the shore to lay their eggs in the beach sand. It is believed that horseshoe crabs have always migrated between the ocean and the shore. If so, they may have developed their migration pattern long before birds even existed, or at least before birds became migrators.

Lobster and Blue Crab move from shallow water to deeper water in the summer.

Shrimp migrate from deep salt water to shallow brackish water.

Fish

Most salt water fish simply migrate from one part of the ocean to another. They move in response to their need to spawn, to feed, and to live in water that has a certain temperature and salinity. These needs may cause them to move from shallow to deep water, from salt water to brackish or even to fresh water, from cold water to warm water or from fresh water to salt water. The migration of some kinds of fish, such as bluefish, which feed on herring, is determined by the migration route of the fish on which they feed.

Atlantic Salmon move into fresh water rivers to spawn. When spawning is finished, the adult Atlantic salmon return to the ocean. They may live to make several return migrations to spawn again in the fresh water.

Eels can live in both fresh and salt water. Eels are common in many streams in Europe and eastern North America. Every fall, adult female eels swim downstream to the sea. At the mouths of the rivers, they meet the males, which have grown to adults in the bays and the waters offshore of the rivers. Here the males join the females in their migration to the spawning grounds in the Sargasso Sea. The European eels may travel a distance of 5000 miles to the calm waters of the Sargasso Sea. The migration of the American eels is less spectacular because it is shorter. It is believed that the adult eels eat nothing from the time their migration begins until after the spawning occurs. Another supposition is that the adult eels die after spawning.

As soon as the eggs hatch, the young eels slowly drift toward their European or American feeding grounds. They grow as they cross the thousands of miles of ocean. When they reach either coastline, the female eels swim upstream where they mature in eight to 12 years. The young male eels do not go into the fresh water rivers; they reach maturity in bays and river mouths.

Haddock, Mackerel, Herring and Cod, all migrate to coastal waters to spawn.

Lake Sturgeon, Lake Smelt, Red Horse, and White Sucker which live in the Mississippi River, move to tributaries to spawn.

Lampreys migrate from salt water to fresh water much as salmon do. Unfortunately for man, lampreys have become so well adjusted to living in the tributaries of the St. Lawrence River and in Lake Ontario that they no longer leave these fresh waters. Because lampreys were killing so many food fish, both the United States and Canadian governments are using methods to destroy the lampreys.

Pacific Salmon are famous migrators. In the north temperate zone, each year from March through the summer months, these salmon from the Pacific Ocean swim into inland rivers and streams during the spawning season. The king salmon may swim upstream in the Columbia River as far as 1000 miles or up the Yukon River as far as 2000 miles. These salmon that survive the long distances and such hazards as waterfalls, dams, and natural enemies will spawn in *autumn* in the headwaters of these rivers.

The eggs *will not hatch until the following spring*. The young fish will swim downstream to the ocean. No evidence has been found that any adult king salmon survive to make the return trip to the ocean.

When the young salmon weigh about 25 pounds, they swim toward the coast, search out the same river where they were hatched, and migrate into it to spawn.

River Herring, also called alewife, migrate to fresh water to spawn.

Shad, Smelt, Sturgeon, and Striped Bass also move from the ocean to fresh water during the breeding season.

Insects

Most insects do not make annual migrations. See Chap. 46, Inquiry 3. Two kinds of butterflies, namely the monarch and the sulfur, are among the few exceptions.

Monarch Butterflies fly south in the fall. They migrate in long thin lines on bright sunny days and rest at night. They may rest for several days before they resume their migration. These butterflies make migrations that may be several hundred miles long. When they reach either California or the Gulf states, they settle on the same trees that have been used for years by other migrant butterflies. In the spring, Monarch butterflies move northward one by one. Only the females travel very far. After the females lay their eggs in their northern feeding range, they die. The monarchs that people see in summer are not the same ones that they saw the previous summer. They are another generation of this species.

The Sulfur Butterfly is known to fly across the Caribbean Sea to its winter range in Bermuda. Very little is known about the migrating habits of other butterflies.

Some kinds of *dragonflies* may migrate, it is believed, but very little is known about their migrations. One kind of ladybird beetle may travel from the garden to the house to spend the winter hidden in tiny cracks around the window frames. Other kinds of ladybird beetles gather together in large masses under leaves and logs and become dormant. Ladybird beetles in the west migrate to places high in the mountains, where they collect in large masses and remain dormant until spring. These masses may be several inches of insects thick.

Reptiles

Some snakes assemble in groups in dens or burrow in the ground and between rocks. They often return to the same place each year.

Green Turtles make the longest migrations. Green turtles are found in all of the tropical oceans of the world. Their nesting beaches are located on the coasts of Africa, Australia, southern Asia, Central America, South America, and Florida. Adult green turtles weigh from 200 to 600 pounds. The turtle is not green but rather an olive color. It was named for the green color of the fat that lines the inside of its shell. There is one beach in the city of Tortuguero, Costa Rica, where several thousands of female green turtles come ashore to lay their eggs in the fine dark sand. The word *Tortuguero* in Spanish means *the place of the turtles*. During the months of July, August, and September, the female turtles crawl out of the surf at night and push their snouts into the wet sand. Why they do this is not known. Some scientists surmise that they smell and feel the sand to find out whether they have come to the right beach.

After this ceremony is completed they move farther onto the beach which is above the level of the highest tides. There, they dig a hole with their hind flippers. The hole will be large enough to hold approximately 100 leathery white eggs which are about the size of a ping pong ball. When a batch of eggs has been laid, the hind flippers are used to cover them with sand. The female may return to the beach on several more nights to complete the laying of her eggs.

The green turtle returns to the ocean to live until the next egg laying season begins. The male turtle never leaves the ocean. He waits near the shoreline for the female.

It is not known where the green turtles go during the period from October until the beginning of the next nesting period. There is some evidence that they may spend their time grazing on the underwater pastures in the Miskito Keys during the daytime and resting on the rocks at the bottom at night.

After the baby green turtles hatch, they crawl over the sand immediately, enter the ocean, and slowly swim away. It is believed that they feed as they go until they reach the feeding grounds of the adult green turtles.

Mammals

Many mammals make short migrations. In this way, they avoid cold, find shelter and new feeding and building places. Only a very few mammals make migrations as long as those of birds. The mammals of the sea are the best known migrators.

Antelopes and Zebras. In warm regions, many mammals migrate and thus escape the dry season. In Africa, antelopes and zebras gather in herds and leave the hot dry lands.

Bats are the only mammals that can fly long distances, as quickly and as easily as most birds do. Bats that spend the summer in Canada may travel south as far as Bermuda. Like other constant-temperature animals that live in cold climates, some kinds of bats hibernate. However, some species of bats do migrate long distances to the caves where they hibernate during the cold of winter. Many thousands of bats may hibernate in the same cave.

Caribou. Many land mammals make seasonal migrations but they do not travel very far. The caribou of the barren grounds of North America roam about in the spring and summer months feeding on lichens, mosses, and grasses in northern Canada and Alaska. The fawns are born in May. By midsummer, the caribou travel in vast winding herds and migrate south to the protective covering of the evergreen forests.

Elephants during the dry season move up into the high mountain forests or into the thick forests in river valleys.

Elk. Elk move from spring and summer pastures when winter comes. The elk in Yellowstone National Park move down from the higher valleys and spend the winter in the Jackson Hole Valley.

Gray Whales. On clear winter days at a certain place overlooking San Diego Bay on the coast of California, people gather to watch the gray whales on their seasonal migrations to their breeding grounds. These whales have feeding grounds in the Arctic and they breed in the quiet protected bays off the coast of Lower California. Young whales, known as the calves, are born there too. The whales do not stay long in these waters. In either March or April, they are on their way back to the Arctic, traveling a distance of 12,000 miles. Just why the whale goes where it does to breed is unknown; but it is not difficult to understand why it returns to the Arctic to feed. Both the gray whale and the blue whale feed on plankton. In summer, the polar seas are rich in these floating islands of plankton. The gray whale also eats krill, a shrimplike crustacean, which feeds on plankton. Both krill and plankton multiply very rapidly during the summer months.

Whales of many kinds migrate in summer to the polar seas where they feed on plant and animal plankton (floating islands of small plants and animals).

Harp Whales travel from Greenland waters to Spitzbergen where they give birth to their snow-white calves.

Northern Fur Seals roam the ocean through the winter months. Each spring, they collect on the shores of the Pribilof Islands in the Bering Sea about 200 miles west of Alaska. The bull seals arrive first and stake out claims for homesites. They wait and watch until the females arrive. As the cow seals arrive, each bull herds as many cows as he can into his territory. By late fall, the breeding grounds are deserted. The seals have headed for the open sea where they will feed on fish and squid.

4. What different types of migration are there? When do animals migrate?

Explore the many patterns of migrators for common factors. Many migrators move from one place to another at *regular intervals.* The *interval* may be an *annual one,* or it may be shorter or longer than a year. The migratory move may coincide with changes in the seasons, with the drive to reproduce, or with other conditions. The migration may take place between:

1. north and south,
2. east and west,
3. highlands and lowlands,
4. shallow and deep water,
5. salt and fresh water,
6. water and dry land.

The common factor of many of the migratory patterns seems to be that they occur *regularly*. They may be typed as *regular migrations*.

If the pupils have not already discovered that some animals that migrate are not regular migrators, suggest they explore the migratory patterns of some of the animals mentioned in the next section. Because these animals migrate only occasionally, they may be typed as *occasional migrators*.

Some interesting information about some occasional migrators

Such animals as short-horned grasshoppers (locusts), bees, the Pallas sand grouse and the various species of lemmings are examples of occasional migrators.

Short-Horned Grasshoppers (locusts) occasionally reproduce in large numbers. When this happens, the young ones gather together in masses and move away from their overcrowded feeding range. As they migrate from one range to another, they strip the leaves from green plants and leave the fields barren. The adult grasshoppers take to the air and make long flights. When this happens so many grasshoppers may be migrating together that they look like huge dark clouds. One such mass of flying grasshoppers, which covered an area of 2000 square miles, was observed over the Red Sea.

Honeybees swarm when the hive becomes overcrowded. Occasionally they swarm and migrate.

Pallas Sand Grouse, natives of central Asia, occasionally have migrated to Europe in great numbers. In 1859 thousands of these sand grouse migrated to Poland, the Netherlands and England but they did not survive in these new feeding and breeding ranges.

Lemmings. Every three or four years, the nesting and feeding ranges of lemmings become overcrowded and hordes of them leave their mountain areas and, in spite of all the obstacles they encounter, they fight their way to the sea, where they drown. This march to the sea may take as long as three years depending upon the course the lemmings take and the distance they have to travel to reach the sea. Thousands of them die enroute from drowning in lakes and streams; many are eaten by their enemies, and some die of a disease called lemming fever. However in spite of their decimation enroute, they propagate so fast that, at the end of their journey, there may be more lemmings than there were when they started.

Lemmings usually do their marching at night. Lemmings are not limited to Scandinavian countries; there is also an American variety. Actually lemmings do not jump into the sea and drown. They are excellent swimmers and are known to swim across lakes and rivers that are several miles wide. In the ocean they drown because they become exhausted, for they never turn back to the shore.

The *adaptations and instincts* of most migrators determine whether the animal *will migrate regularly or occasionally*. Do other animals without adaptations and instincts to migrate, ever establish new feeding and breeding ranges? The following information samples some of the *accidental migrations* that occur.

Some interesting information about accidental migrations

In the Pacific Ocean, many tiny, barren, coral islands are produced. At first, the corals are the only animals on these islands. It will not be too many years, however, before these islands will have many different kinds of animals on them. How do they get there? It is easy to explain the arrival of those animals that can swim and fly. But how can the presence of animals that can neither swim nor fly be explained? (They may have floated in on rafts of floating plant materials. Possibly they rode on floating driftwood from mainland areas. Small animals may have arrived clinging to the feet and feathers of birds. The tiniest ones may have been carried aloft by the wind only to be deposited later on these new islands. Ocean currents play a part in accidental migration also. All floating objects may accidentally carry animals. If these animals survive, they may be propelled long distances by the ocean currents. The smallest land animals may have come in this way.)

In 1883, a small volcanic island off Java blew up. Only one kind of soil was left there. All living things were killed. Fourteen years later, there were spiders, flies, true bugs, beetles, butterflies, and moths living there. Forty-five years later, a great many kinds of animals lived on the island. In addition to insects and other kinds of very small animals, there were land snails, birds, bats, rats, lizards, one kind of crocodile, and one kind of snake.

Accidental or chance migration can also populate man-made ponds and lakes. For thousands of years people have helped to introduce animals into new regions. They have done this both *knowingly* and *unknowingly*. When man unknowingly introduces an animal to an area this, too, is accidental migration.

Rabbits now live in all parts of the world except the Antarctic. Man has introduced them purposely into certain regions. There were no rabbits in Australia until man brought them there.

Barnacles have traveled long distances on the bottoms of ships. Rats have been widely distributed by hiding in cargoes. Some of the worst insect pests, such as the European corn borer, the Mediterranean fruit fly, the fire ant, the Japanese beetle, and the San Jose scale, also have been accidental migrators.

Such animals as the English sparrow, the starling and the ring-necked pheasant were knowingly introduced into the United States. So, too, was the praying mantis.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Migratory and nonmigratory birds are found in many different regions of the world. Climate and the physical and biological environment determine the kinds of birds that live in a certain region.

There seems to be a relationship between the feeding habits and the kinds of birds that migrate. In regions where the winters are long and cold, nonmigratory birds feed chiefly on small animals that live either in shrubs and trees or on seeds and fruits that cling to tall plants. Most birds who do not eat this kind of food migrate.

2. In winter, nonmigratory birds have a thick layer of *down* under their contour feathers. This layer of *down* traps the heat that is radiated from the bird's body.

Each kind of migratory bird follows a set time and route. Some migrate long distances; others only short distances.

There are four flyways that birds of North America take when they migrate either to the north or to the south. Most birds use the Mississippi Flyway. The Mississippi Flyway has plenty of food and fewer natural hazards than the other flyways. In the United States, migration is more common in the central and eastern states than it is in the western states.

The Arctic tern is known for the long distance it travels in its migration. The Arctic tern makes a round trip to the south temperate zone or to the Antarctic each year.

Many kinds of birds in the north temperate zone tend to migrate to feeding ranges in warmer climates to the south in the fall and to return to their northern nesting ranges in the spring. Other kinds of birds migrate to the west in the fall and to the east in the spring. Migration is more common in the north temperate zone than it is either in the south temperate zone or in the tropics. Most kinds of birds in the south temperate zone do not migrate. The ones that do migrate travel to warmer climates in the north during the local fall and to the south in the local spring season.

3. Various kinds of amphibians, crustaceans, fish, insects, reptiles, and mammals migrate.

4. There are several types of migration. They are referred to as *regular*, *occasional*, and *accidental*.

Regular migrators usually migrate seasonally, annually, or more commonly at regular short periods. Whatever their migration pattern may be, it is repeated at regularly defined intervals.

Occasional migrators may migrate at any time. Their migration does not take place at regular intervals.

Accidental migrators are carried to new areas by the forces of nature, man, and other animals.

Chapter Forty-Eight

Worldwide Distribution of Animals

INQUIRY

1. Why do some kinds of animals live in only a few regions of the world? Why are other kinds of animals so much more widely distributed?

1. Why do some kinds of animals live in only a few regions of the world? Why are other kinds of animals so much more widely distributed?

Discuss the unique animals of the world and speculate why they live where they do. After the discussion period, assign reference reading to help pupils locate information similar to that which follows.

Approximately one million different kinds of animals live on the land and in the sea. Many of these different species of animals can live only in a *single region.* Others can live in *many different kinds of environment.* An animal which continues to live in a particular habitat must be able to find there the things that are necessary for its survival.

Some parts of the world are crowded with animal life. In a few regions, no animal life has been found. To understand why animals live where they do and how they move about over the world, one needs to know about various kinds of climates, vegetation, and soil. See Chap. 44, Inquiry 5.

Climate is chiefly a matter of temperature and rainfall. The tropics receive so much heat and light that they are hot throughout the year. The polar regions receive so little heat and light, even in the polar summer, that they are always cold. The amount of rainfall that a region receives depends upon the direction of the winds, location of mountain ranges, and on the size, location and character of bodies of water. The chief sources of rain are the oceans. Water from the ocean is evaporated into the air as the winds move over the oceans. This water travels in an air mass until it condenses and falls to the ground in the form of rain, hail, or snow.

Most regions in the tropics have a great deal of rain; most of the deserts of the world very little. Most deserts are located between ten and 25 degrees north latitude and ten to 25 degrees south latitude. Some other deserts of the world are located in the Arctic and Antarctic. Still other deserts are man-made. These man-made deserts can be located anywhere in the world where the average annual rainfall is between ten and 20 inches.

The kinds and the abundance of plants that grow in a region vary with the climate. To some extent, the kinds of animals that are found in a region vary with the climate and the kinds of vegetation. South of the permanent ice and snow of the north polar region, there are *tundras* where plants are *small and sparse*. The tundras give way to the *northern evergreen forests*. Farther south, the evergreen forests are replaced by *deciduous forests*. The deciduous forests give way to the *tropical rain forests*. Within the large plant communities, there are many regional variations caused by such factors as ocean currents, distance from the sea, and altitude. These factors affect the local climate, the varieties of vegetation and the kind of animals that live in these regions.

Even a simple map, illustrating the worldwide distributions of plants, shows that different kinds of vegetational growth are not located in even, uniform bands around the world.

More of the earth's surface is covered by water than is covered by land. The climates of the different oceans vary less than the climates of the different land regions. For example, *many aquatic plants and animals* are present in the oceans around the two polar regions; but *only a few land plants and animals* live in these areas.

Both green plants and animals tend to produce more offspring than a region can support. When abundant, animals spread beyond the natural boundaries of their region. This behavior is an important factor in their survival. It is also an important factor in the dispersal of animals on the earth. This kind of dispersal is limited by such factors as the animal's ability to adjust to a different region, to a different food supply, and by natural barriers which bar their dispersal. The most widely distributed animals are insects, rabbits, rats, mice, squirrels, birds, and such aquatic animals as fish. These animals have adaptations that enable them to live in many different regions. Their feeding habits are also well adjusted. They eat a greater variety of foods than many other kinds of animals that are more limited in their distribution. Large herds of bison, which formerly roamed over the grasslands of the plains of North America, could not disperse southward because of the absence of grasslands in the southern part of the United States and in the northern part of Mexico. Such natural barriers as oceans and mountain ranges also limit the dispersal of animals from one region to another.

For many years, the distribution of animals on the earth was considered to be haphazard because there did not seem to be any logical explanation for it. Now there is considerable evidence to support the theory that geological changes in land masses are factors that have affected the distribution of animals. Geologists believe that *North America was formerly connected to Asia* by a narrow strip of land. Today, this strip of land has disappeared and the area in which it was located is known as the *Bering Straits*. However, if this strip of land did connect North America and Asia in the past, the similarities between the animals on these two continents can be understood. Scientists believe that many millions of years ago, animals dispersed freely across this land bridge from one continent to another.

Geologists also think that North and South America *were once separated*. If this is true, the differences between the animals that live on these continents can be understood. Because no *carnivorous*, land mammals live in South America, it seems likely that no connecting land mass existed between North and South America when these carnivores evolved.

It is believed that many millions of years ago, Australia was connected to the continent of Asia. If this theory is true, it helps to explain why such marsupials as the banded anteater and the duckbill platypus are limited to Australia. These marsupials probably evolved in Australia after it was separated from Asia. Also, because no placental animals are native to Australia, it is assumed that this continent was separated from Asia before these animals evolved.

After discussing the information that the pupils have found in their reference reading, help them to locate maps which show *the worldwide distribution and limitations of animals.* Call attention to the zoological zones. Observe that each different zone tends to be confined to one continental land mass. Also develop the concept that although some of the animals that live in a zone differ, there are many similarities.

CHAPTER SUMMARY OF SCIENTIFIC FINDINGS

1. Many of the different species of animals that live on the earth are adapted to live in a particular region. Other species can live in many different kinds of environments. An animal that continues to survive in a particular habitat does so because all the things necessary for its survival are present. Some parts of the world are crowded with animal life. In a few regions, no animal life has been found.

Climate is chiefly a matter of temperature and rainfall. Because the tropics receive much sunlight, they are hot throughout the year. Because the polar regions receive little sunlight, they are almost always cold.

The amount of rainfall a region receives depends upon its location. The oceans are the chief sources of rain. Most regions in the tropics have a great deal of rain; most of the deserts of the world very little. Most of the deserts of the world are located between ten and 25 degrees north and south latitudes and receive between ten and 20 inches of rainfall a year. To some extent, the kinds of animals that are found in a region vary with the climate and the vegetation.

The fact that many animals move from one region to another is an important factor in their survival. It is also an important factor in their dispersal over the world. The dispersal of animals is limited by such factors as their ability to move and to become adjusted. Their dispersal is also limited by such natural barriers as mountains and bodies of water.

Changes in the relationships between land masses and oceans in the geological past may explain the reason for the limited distribution of some species of animals. Although there are some differences between the animals found in different regions, there are also many similarities.

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Chapter 42

SUMMARY OF PROCESS SKILLS—OBSERVING A GARDEN AT THE END OF THE GROWING SEASON

	Inquiries																
Process Skills for Critical Inquiry*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Observing	✓	✓	✓														
Classifying	✓	✓	✓														
Measuring	✓	✓															
Recognizing space time relationships																	
Recognizing number relationships	✓																
Communicating	✓	✓	✓														
Inferring	✓	✓	✓														
Predicting		✓	✓														
Formulating hypotheses		✓	✓														
Making operational definitions	✓	✓	✓														
Controlling and manipulating variables		✓															
Experimenting		✓															
Interpreting data		✓															
Formulating models		✓															

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* Arthur H. Livermore, "The Process Approach of the AAAS Commission on Science Education," *Journal of Research in Science Teaching* (1964), II, 271–82.

Chapter 46

SUMMARY OF PROCESS SKILLS—OBSERVING ANIMALS DURING THE SEASONS WHEN THEY ARE MOST ACTIVE AND LEAST ACTIVE

	Inquiries																
Process Skills for Critical Inquiry*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Observing	✓	✓	✓														
Classifying	✓	✓	✓														
Measuring																	
Recognizing space time relationships																	
Recognizing number relationships	✓																
Communicating	✓	✓	✓														
Inferring	✓	✓															
Predicting	✓	✓															
Formulating hypotheses	✓	✓															
Making operational definitions	✓	✓	✓														
Controlling and manipulating variables	✓	✓															
Experimenting	✓	✓															
Interpreting data																	
Formulating models	✓	✓															

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* Arthur H. Livermore, "The Process Approach of the AAAS Commission on Science Education," *Journal of Research in Science Teaching* (1964), II, 271–82.

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